天津大学硕士学位论文

# 水资源规划与城市可持续发展——河北省衡水市的案例分析

# Water Resources Planning And City Sustainable Development. A Case Study Of Heng Shui City, Hebei Province, P.R.China

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# 中文摘要

正如中国许多流域一样，滏东排河流域的水资源已几乎得到充分的分配。所谓的“水库”（以解决人和环境需水为目的的径流贮存地）也给衡水市的水资源管理增加了新的问题，特别是在旱季的时候。本论文试图将水资源评价与管理模型（WEAP）应用于滏东排河衡水流域来实现评价水资源利用中存在的问题。本模型可以用来模拟和分析各种水资源分配方案，特别是用户行为方案。水资源需求管理是本文一项详细论述的内容。文中讨论了枯水年到平水年气候条件，人口增长率，灌溉效率改进和技术进步因素下的模拟，以及水质、水库、集水地的模拟预测结果。显然，数据的存在和可靠十分关键，需要认真对待和仔细判断。其次，基于用水的合理的假设需要作出结论以支持决策。在数据有限的情况下，仍然可以发现河流无法满足水资源用户需求要求，有些年份甚至生态需水也无法满足。但在正常年份采用水资源需求管理可以为缓解这个问题提供了机遇。然而在干旱年份这个办法则无法平衡供需矛盾。模型的易用性以及友好的用户界面使得水资源管理中相关利益方的讨论和对话变得容易，它也为提升公众的认识提供了帮助。总之，消除水资源紧缺状况涉及到中水存蓄，水价机制，包含滏阳新河的扩展模型，外调水，水库增容与新建，污水处理厂，信息传播等等，以上这些如果能够施行必将极大地提升城市的水资源可持续利用和可持续发展，而这也正是这个城市所致力追求的目标。

**关键词：** 水资源分配　WEAP 模型　水资源需求管理　流域管理　水资源管理　滏东排河　衡水湖

# ABSTRACT

Like many river basins in China, water resources in the Fu Dong Pai River are almost fully allocated. Respecting the so-called “reserve” (water flow reservation for basic human needs and the environment) imposed by the country adds a further dimension, if not difficulty, to water resources management in Heng Shui City, especially during the dry periods. This paper seeks to assess and evaluate water resource problems using the Water Evaluation and Planning (WEAP) model for this purpose via its application to the Heng Shui basin of the Fu Dong Pai River. This model allows the simulation and analysis of various water allocation scenarios and, above all, scenarios of users’ behavior. Water demand management is one of the options discussed in more detail here. Simulations are proposed for diverse climatic situations from dry years to normal years, population growth, improved irrigation efficiency and slight technological impact, water quality, reservoir and catchment (RAO Runoff, Soil Moisture Method, and Surface Water-Groundwater Interaction) and their results are discussed. It is evident that the availability and reliability of data is very crucial and must be dealt with carefully and with good judgment. Secondly, credible hypotheses were made about water uses (losses, return flow) for the results are to be meaningfully used in support of decision-making. Within the limits of data availability, it appears that most water users are not able to meet all their requirements from the river, and that even the ecological reserve will not be fully met during certain years. But the adoption of water demand management procedures offers opportunities for remedying this situation during normal hydrological years. However, it appears that demand management alone will not suffice during dry years. Nevertheless, the ease of use of the model and its user-friendly interfaces make it particularly useful for discussions and dialogue on water resources management among stakeholders; it can also be used to promote greater awareness and understanding of key issues and concerns among the public. Above all, solutions to remedy this ugly water scarcity scenarios ranges from Building reused water reservoir, Water Pricing, Expansion of the model to include New Fu Yang River, Inevitable water importation, Increasing reservoir capacity and building new ones, Increasing Waste Water Treatment Plant, Information dissemination, Development of professional manpower and Model Extension, these if adequately enforced will bring a great relief to water sustainability and city development which this paper and the city seek to pursue.


**Key Words:** Water allocation, WEAP model, Water demand management, River basin management，Water resources management，Fu Dong Pai River，Heng Shui Lake

# 目　　录

# CHAPTER ONE

## Introduction.

Water resources management is one of the most important challenges the world faces. It is difficult to think of a resource more essential to the health of human communities or their economies than water. Humans cannot live for more than several days without water, shorter than for any source of sustenance other than fresh air. In meeting their demand for water, societies extract vast quantities from rivers, lakes, wetlands, and underground aquifers to supply the requirements of cities, farms, and industries. There is also growing recognition that functionally intact and biologically complex freshwater ecosystems provide many economically valuable commodities and services to society (ecosystem services) beyond simply direct water supply. These services include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals, and production of fish and other foods and marketable goods. These ecosystem benefits are costly and often impossible to replace when aquatic systems are degraded. Deliberations about water allocation should therefore, always include provisions for maintaining the integrity of freshwater ecosystems, including the need to maintain minimum in-stream flows and to anticipate the impact of hydrologic modifications on downstream environments (Flint et al. 1996). Otherwise, there have few safeguards that will protect the systems that sustain us.

Managing water resources in the current world climate is a major challenge for many countries. It is widely recognized that there are an increasing range of drivers directing current water management practice – pressure of climate change and extreme events on water resources and food security, the awareness and importance of city sustainability, community factors such as urban growth and education and the economics of water trading and infrastructure. This papers perspective ensures that these factors are taken into account in the management and development of water resources.

Freshwater resources are an essential component of the Earth's hydrosphere and an indispensable part of all terrestrial ecosystems. The freshwater environment is characterized by the hydrological cycle, including floods and droughts, which in some regions have become more extreme and dramatic in their consequences. Global climate change and atmospheric pollution could also have an impact on freshwater resources and their availability and, through sea-level rise, threaten low-lying coastal areas like that of Heng Shui City

There is no doubt that water is needed in all aspects of life. Making it a necessity to adequately supply water of good quality that will maintained the entire population of

Heng Shui Municipality, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases is the upmost priority. Innovative technologies, including the improvement of indigenous technologies, are needed to fully utilize limited water resources and to safeguard those resources against pollution and scarcity.

In general, there are five types of water problems in China: water shortage, flooding disasters, water pollution, groundwater over-exploitation, and poor water resources management (Zhang and Zhang, 1995, 2001 and 2002). In light of severe water shortage and water quality degradation in major rivers, lakes and coastal water bodies, two most challenging issues in Sustainable Eco-City Development is water resource and ecosystem integrity.

## 1.1 Objectives

The overall objective is to satisfy the freshwater needs of Heng Shui for their sustainable city development. Sustainable water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and social and economic goods, whose quantity and quality determine the nature of its utilization. To this end, water resources have to be protected, taking into account the functioning of aquatic ecosystems and the perenniality of the resource, in order to satisfy and reconcile needs for water in human activities. In developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems. Beyond these requirements, however, water users should be charged appropriately. In order to carry out water resources management and sustainable city development, four principal objectives should be pursued, as follows:

(a) To promote a dynamic, interactive, iterative and multisectoral approach to water resources management, including the identification and protection of potential sources of freshwater supply, that integrates technological, socio-economic, environmental and human health considerations;

(b) To plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of China's national economic development policy;

(c) To design, implement and evaluate projects and programmes that are both economically efficient and socially appropriate within clearly defined strategies, based on an approach of full public participation, in water resource management policy-making and decision-making;

(d) To identify and strengthen or develop, as required, in particular to Heng Shui, the appropriate institutional, legal and financial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable development, social progress, and economic growth.

## 1.2 Problem Definition/Statement

The foregoing has led many observers to conclude that the major wars of the twenty-first century will be over water rather than oil or other resources, Dellapenna (Gleick 1998). Remarkably, with all the rivalry and potential for conflict, very few, if any, conflicts in recent centuries have in fact been over water resources (Wolf 1998). If conflict is to be avoided, States sharing a water resource must undertake to create and implement legal mechanisms for resolving disputes and for cooperatively managing the resource. And that development must be sustainable over time, or arrangements must certainly break down, with conflict ensuing (Birnie and Boyle 2002). This has been recognized—albeit only in summary fashion—in the two most recent authoritative statements of the customary international law of transboundary waters (International Court of Justice 1997; United Nations Convention 1997, art. 5). The emerging legal requirement that the development of water (and other resources) be sustainable is open to considerable debate about its meaning and application (Boyle and Freestone 1999; Carley 1998; United Nations Commission 1997). Furthermore, the requirement often is found in "soft law" instruments (Brown Weiss 1999; Dupuy 1991; Shelton 2000; Young 1998). This paper briefly examines the emerging norm of sustainability and considers the question of whether; at least in its present state of development, that norm can serve as a useful criterion for water management.

Freshwater is a unitary resource. Long-term development of global and municipal freshwater requires holistic management of resources and recognition of the interconnectedness of the elements related to freshwater and freshwater quality. There are few regions of the world that are still exempt from problems of loss of potential sources of freshwater supply, degraded water quality and pollution of surface and groundwater sources. Major problems affecting the water quality of rivers and lakes in Heng Shui arise, in variable order of importance according to different situations, from inadequately treated domestic sewage, inadequate controls on the discharges of industrial waste waters, loss and destruction of catchment areas, ill-considered siting of industrial plants, scarcity, deforestation, uncontrolled shifting cultivation and poor agricultural practices. This gives rise to the leaching of nutrients and pesticides. Aquatic ecosystems are disturbed and living freshwater resources are threatened. Under certain circumstances, aquatic ecosystems are also affected by agricultural water resource development projects such as dams, river diversions, water installations and irrigation schemes. Erosion, sedimentation, deforestation and desertification have led to increased land degradation, and the creation of reservoirs has, in some cases, resulted in adverse effects on ecosystems. Many of these problems have arisen from a development model that is environmentally destructive and from a lack of public awareness and education about surface and groundwater resource protection.

Ecological and human health effects are the measurable consequences, although the means to monitor them are inadequate or non-existent in Heng Shui Municipality. There is a widespread lack of perception of the linkages between the sustainable development, management, use and treatment of water resources and aquatic ecosystems. A preventive approach, where appropriate, is crucial to the avoiding of costly subsequent measures to rehabilitate, treat and develop new water supplies and hence sustaining the city development. This and other things are what this paper tends to achieve.

## 1.3 Project Justification:

The extent and severity of contamination of water resources have long been underestimated owing to the relative inaccessibility of these resources and the lack of reliable information on management systems. Ground water is not a nonrenewable resource, such as a mineral or petroleum deposit, nor is it completely renewable in the same manner and timeframe as solar energy. So the protection of both surface and ground water is therefore an essential element of water resource management "If sustainable development is to mean anything, such development must be based on an appropriate understanding of the environment (the Heng Shui City inclusive)--an environment where knowledge of water resources is basic to virtually all endeavors." *Report on Water Resources Assessment, WMO/UNESCO, 199*1. Hence it has become imperative to consider water utilization, water resources management and city sustainable development for some obvious reason, one water is a finite resource and the basis of live, it is very scare and precious resource when it is maximally used, though considering the growing population, it usage could be abuse and consequent dearth could result, China as an example is face with enormous task of water shortage, and the only solution to this is water management, through planned sustainability to cope up with the challenges in the near future. With hope, this will bring to the highlight of the impending reality that the city is going to be face with, except we act fast.

Water shortage and water quality pollution problems are two most challenging water issues in China, especially when many large metropolitans are striving for sustainable eco-city development. Water is not an inexhaustible resource and has become a limiting factor to fast-growing economic development in China. Realizing the water issue is also a social problem that the pure scientific method can no longer solve, comprehensive efforts combining the technological, economic, planning and legal measures, together with improved social awareness of sustainable development are needed to build green and sustainable eco-cities. Appropriate measures will be formulated based on Management and Sustainable principle, which will emphasizes few basic approach, and enhancement of ecological integrity and ecosystem balance of Heng Shui Municipal areas.

## 1.4 Area of Contribution

This However studies on water resource management and city sustainability development are very rare in Heng Shui considering the size of the city, given the financial implications involve in the management of water resource, the relative newness of the city itself and it implication to future sustainability. This paper will highlight some points that if properly implemented will strategically place the city in the pinnacle of development, thus adding to the growth both economically and socially to China's rapidly developing economy and hence studies like this have become necessary, from a sustainability perspective, the key point is that sustainable decisions today will affect surface-water availability; however, these effects may not be fully realized for many years. However, it will reasonably contribute to knowledge and our developing economy.

## 1.5 Research Methodology

This study involves both primary and secondary data, which would compliment each other. A wide range of simulation tools would be employ in the study analysis. The methodologies would establish the success or the failure or the under utilization of water resource management in this city which could likely lay the basis for comparative planning utilization and sustainable development. In the cause of the studies some management statistical analytical tools will be use for future predictions with respect to water supply, importation and utilization; and the Quadratic Regression Model which from standardized residual test, is found to be the best appropriate test model for Supply verse Utilization component, taking other factors into consideration. In the cause of the research, for each component tested, two hypotheses is drawn, Known as the Null and Alternate Hypothesis, a significant value of 95% that is 0.05 was used to test for the significance of the hypothesis and the then conclusion and decision is made.

In the past different approach have been used for other large cities but this project intend to use Water Environmental Simulation Model (WEAP). These methods are definitely complimentary in several ways and as such would be applied in the study.

## 1.6 Scope and Limitation

The study focus on water resources management which covers both surface and ground water with positive implication towards the city (Heng Shui) sustainability, a close reference would however be made frequently in an attempt to ensure a robust analytical presentation. Some limitations were encountered in the area of getting material in other language other than Chinese for historical background and comparative studies, though self translation was done, not without great difficulties and also by omission or commission, some vital data background could be lost during the translation process.

## 1.7 Thesis Structure

Chapter One, Introduction; this chapter introduces the aim and objective of this study, it purposes execution, the area of contribution in nature, it scope and research methodology, and the project limitation.

Chapter Two, The Literature Review; This take an in-depth analysis of global, national and local water problems, it review some of the article that were needed for this research.

Chapter Three, The Study Area; This also take a brief and precise look of the study area from different perspectives, such as Climatic, Hydrological, Ecological, Geological, and Economical.

Chapter Four, Presentation of Data; this area bother on various field data that were use for future prediction and simulation model, the chapter applied some statistical tools such as MINITAB for future water demand prediction.

Chapter Five, Modeling Water Demand and Supply; as well present data acquisition from different models, Identification of the data and this process involved in linking the data to build the model. Scenario Development and Analysis; building possible scenarios to run the model, computing the results, and analysing the results from the different scenarios.

Chapter Six present Summaries, Conclusion and Recommendations.

# CHAPTER TWO

## Literature Review

Water suitable for human needs is an increasingly scarce resource, particularly when viewed against the backdrop of an expanding global population (Diaz and Dubner 2001; Engelman and LeRoy 1997; Gleick 2002; Postel 1999). The exponential growth of the human population in the twentieth century was not the only force driving demand for water, for *per capita* consumption has grown even faster than human populations in most parts of the world (Dellapenna 1997; La Rivière 1989; United Nations Commission on Sustainable Development 1997). The prospect of global climate change could worsen this situation dramatically (Abu-Taleb 2000; Bazzaz 1994; Symposium 1999; Symposium 2000). Fresh water is, however, one of the most essential resources for human survival, let alone for human thriving. Deprive us of air, and we die in minutes. Deprive us of water, and we die in days. Deprive us of food, and we can go on for weeks or months—as inmates of concentration camps or persons on hunger strikes have demonstrated. And, as a Turkish businessman recently commented, “Countless millions of people have lived without love, but none without water” (Nachmani 1994). Whether that last is true, the point remains—there is a continuum of needs for humans and other entities, and water stands very near the end of the continuum because without it life cannot survive for any significant length of time.

While water is found nearly everywhere, water for our essential needs is often in the wrong place, inadequate in amount, or too impure. For example, annual precipitation in Egypt amounts to a mere 50 cubic meters per person, while in Zaire annual precipitation produces 76,000 cubic meters per person (Kukk and Deese 1996). Furthermore, precipitation patterns usually vary considerably with the season. Spring floods are often followed by summer droughts. The qualitative variability of water—one of the aspects of water that makes it so useful to us—means that pure water is a manufactured product that simply does not exist in nature. Humans and most plants and animals of use to humans can tolerate only a narrow range of impurities in the water they consume. Water has one other quality that, when combined water’s unusual importance, gives rise to considerable risk of conflict among neighboring nations or communities (McCaffrey 2000; Vayrynen 2001). Water is an ambient resource that largely ignores human boundaries. Some 264 river basins in the world—home to nearly 50 percent of the world’s population—are shared by more than one nation (Wolf 1998).

Water is present in abundant quantities on and under Earth’s surface, but only less than 1 percent of the Earth’s water is actually available for use in economically satisfying the needs mentioned. Most of the Earth’s water is frozen in the polar ice caps. Many freshwater lakes and rivers have been deteriorating in quality because of land development and pollution, limiting the availability of water for use, particularly for public water supplies. Even groundwater is affected by pollution in some areas, although much of it is just too deep to pump out of wells economically.（Jerry A Nathanson 2003).

In 1988, a UN conference of 84 nations was held to discuss management of the world's limited supply of freshwater. It was estimated at the conference that about one quarter of the world's 5.9 now 6.5 billion people have no access to clean drinking water, the much being Asia and Africa. The conference delegate agreed that water should be paid for as a commodity rather than considered an essential staple to be supplied virtually free of cost. Water shortages are so important that government may need to rely on private fund for large investment needed for water networks and treatment system. Because of it dearth nature, water is sustain in human communities through hydrologic cycle. Water is withdrawn from its source in the natural hydrologic cycle----surface waters of groundwater---and is pumped through treatment and distribution systems. After use, the wastewater is collected in sewer systems, treated to reduce the effect of pollution, and finally disposed of back into surface water or groundwater. A most significant aspect of city sustainability is maintenance of this urban water cycle while protecting public health and environmental quality.

In general, the time has passed when abundant supplies of water were readily available for development at low economic, social, and environmental costs. Now we are in what Hufschmidt (1993) called the period of the "maturing water economy," with increasing competition for access to fixed supplies, a growing risk of water pollution, and sharply higher economic, social, and environmental costs of development .Few areas of public policy are as contentious as the management of our water resources. Around the world, most of the easily developable water has been developed, and future water management will depend on obtaining more out of existing supplies.

The great challenge facing the world today is how to cope with the impact of economic growth on the environment. Sustainable development emerged during the late 1980s as a unifying approach to concerns about the environment, economic development, and quality of life. The World Commission on Environment and Development (1987), better known as the Brundtland Commission, defined *sustainable development a*s "development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Resource sustainability has proved to be an elusive concept to define in a precise manner and with universal applicability. In this report, we define ***water resources sustainability*** as development and use of all kinds of water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences. The definition of "unacceptable consequences" is largely subjective and may involve a large number of criteria. Furthermore, water resource management and sustainability must be defined within the context of the complete hydrologic system of which the entire city of Heng Shui is a part. ”

This intergenerational perspective implies that we must use the water resources in ways that are compatible with maintaining them for future generations, thus constraining our management of water. Although progress has been made in defining the goals of sustainable development, the mechanisms to bring about these changes are still a matter of debate. *The challenge is to turn the principles of sustainable development into achievable policies*. The move from principle to practice is far from easy. Like other abstract concepts, sustainable development is a powerful and dynamic concept that will continue to be refined. Science can explore the implications of different interpretations of sustainability, but it cannot choose the “correct” interpretation for society. Nonetheless, if sustainable development of water resources is to have any meaning, it must be based on sound hydrologic analyses and appropriate technologies. This paper represents a critical synthesis of water sustainability issues from the hydrologic perspective. The focus on Heng Shui is intended to emphasize selected applications of the concepts presented.

The utilization of surface and groundwater is subject to socio-economic, institutional, legal, cultural, ethical and policy considerations. However, its beneficial use is often constrained by weak social and institutional capacity, and poor legal and policy frameworks. This difficulty may become significant in transboundary aquifers because of contrasting capacities and institutional frameworks on each side of a boundary. Attention has to be given to critical elements such as capacity building, participation, raising awareness, investment and appropriate technology.

Often due to lack of standard monitoring procedures available data cannot be compared and are inadequate to plan regional action for the sustainable development and use of shared groundwater. Clearly, for beneficial use of shared groundwater it is necessary to evaluate and map all potential damaging impacts. This is of particular importance because the impacts may be subtle, widely spread in space and delayed in time. Due to the lack of reliable scientific knowledge and information conflicts may arise. To avoid conflicts water resources have to be managed in an integrated way, based upon, collection, analysis and sharing of reliable information on the aquifers at national and regional level. Says, the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes, brokered by the United Nations Economic Commission for Europe (UN/ECE)

In total, less than three-tenths of 1% of Earth’s freshwater is in the lakes and rivers that have severe. In an era of global water shortage, probably no goals are more important than achieving the sustainability of water resources. Considering the definition put forward by Peter Gleick and his colleagues at the Pacific Institute. They define sustainability as “the ability of human society to endure and flourish into the indefinite future without the use of water that supports undermining the integrity of the hydrological cycle or the ecological systems that depend on it” (Gleick et al. 1995; Birnie and Boyle 2002; Fuentes 1998). Laudable goals, but how do we translate this into concrete decisions. No wonder some declare that the concept of “sustainability” is only a slogan in environmental battles rather than an actual criterion of policy choice (Esty 1998; Ruhl 1999). That water resources are finite and that aggregate demand is approaching or exceeding the available water supply requires that sustainability be the pervasive criterion of both public and private water management (Fuentes 1998; United Nations Convention 1997, art. 5).

Yet one can never be certain that one is managing current use in a fashion that will not compromise future need. At the least, sustainable use requires viewing water resources as parts of ecosystems that can be managed effectively only by giving careful attention to the interconnections of the parts of the system (Korhonen 1996; Symposium 1994; Symposium 1997). In particular, one must ask whether, for a renewable resource such as water, the criterion ought to be "sustainable development" or "sustainable use." as the major sources of water through most of human history (Adler 2002), but societies worldwide have not always appreciated this easily accessible freshwater and the need to protect it. Thus, water consumption has nearly doubled since 1950 (UNESCO 2003), and much of the world suffers greatly from inadequate access to potable water. About 20% of the Earth's population of 6.5 billion lacks access to safe drinking water (Hall 2003). According to the United Nations, more than 200 million people every year suffer from water-related diseases, and about 2.2 million of them—mostly the poor—die. The demand for water resources is continuing to increase. This increase is being driven not only by a growing world population but also by the aspirations of that population for an ever-increasing standard of living (Bartlett 1999). At the same time, the capacity of the planet to meet this demand is in decline because of over-harvesting, inappropriate agricultural practices, and pollution, to name just a few. These impacts on Earth are occurring because humans are not in line with the way the natural world functions. Currently a large proportion of the world's population is experiencing water stress (Table 1). Rising population demands for water from irrigation (70% of all water uses), industrial (20%), and residential (10%) uses greatly outweigh greenhouse-warming affects on world water supplies (Vorosmarty et al. 2000). Likewise, humans use more than 50% of the available freshwater in our world, 60% of which is wasted, leaving less than half for all other life forms on Earth. The average quarter-pound hamburger requires 616 gallons of water to create its meat; the cheese requires 56 gallons; and the making of the bun 25 gallons of water (Ryan 1997). The average U.S. household uses about 50 gallons per person per day, a rate more than seven times the per capita average in the rest of the world and nearly triple Europe's level. Yet the World Health Organization says good health and cleanliness require a total daily supply of about 8 gallons per person per day (Table 1). Other signs are just as frightening (Table 1). In 1986, a study statistically linked children with leukemia in Woburn, Massachusetts to contaminated drinking water affected by a waste site nearby. A study released in 1995 has shown that herbicides in drinking water exceed federal safety levels in 29 cities and towns in the U.S. corn-belt. Israelis and Palestinians have argued for years over how to share the Mountain Aquifer, which lies beneath the West Bank. Pakistan and India have engaged in conflict for centuries over water rights to the Indus and Ganges

Rivers.

Society is “hitting the limits” or hitting the wall of a funnel, as in The Natural Step (Robert 1991; Gips 1998), in its never-ending use of natural resources and production of waste. The situation of the people on Earth can be viewed as a funnel with ever diminishing room to maneuver. Life-support systems for our continued existence on the planet are in decline. At the same time, the global population and global demand for these resources are increasing, leading us to “hit the wall” of the funnel. Increasing water shortages or inequitable access to safe water can cause poverty and environmental degradation that can lead to global hunger, resulting in civil unrest and human conflict. With conflict comes a regional and national dispute, even war that can best be alleviated by the sustainable use of these resources.

**Table 1**. Why Be Concerned About Our Water Resources?

| Water Resource Availability | How Safe Is Our Water? | Water and World Security |
|---|---|---|
| Average U.S. household uses about 50 gal/person/day, nearly triple Europe's level and more than 7 times the rest of the world (ENS, 1999b). | In 1996, 263 million tons of Nitrogen and 18 million pounds of Phosphorus ran into the Chesapeake Bay (ENN, 1998). | Israelis and Palestinians have argued for years over how to share the Mountain Aquifer beneath the West Bank (Edie Summaries, 2000). |
| The World Health Organization says good health and cleanliness require a total daily supply of about 8 gal/person/day ( Collier, 1999). | Fish advisories for risks to human health have become a standard practice of the 1980s and 1990s (ENN, 1999). | Pakistan and India have been in conflict for centuries over water in the Indus and Ganges Rivers, which both originate in Kashmir (Mustikhan, 1999). |
| Two-thirds of residential interior water is used for toilet flushing (4 gal/flush) and bathing (15-50 gal/shower or bath) while a dishwasher uses 8-12 gal and a top-loading clothes washer 40-55 gal (ENS, 1999b). | In 1986 a study statistically linked children with leukemia in Woburn, Massachusetts to contaminated drinking water affected by a nearby waste site (Montague, 1998). | While the Syrians press for an Israeli withdrawal from the Golan Heights, water, not land is the crucial issue between the two countries. The Golan Heights provides more than 12% of Israel's water requirements (Edie Summaries, 2000). |
| Land irrigation pumping extracts underground water much faster than it is replaced and spray irrigation loses 1/3 of water to evaporation before reaching plant roots (Lazaroff, 2000). | Clusters of child leukemia are occurring in regions where drinking water has been contaminated by carcinogenic volatile organic compounds from industry (Sutherland, 1999). | The Nile River in Africa runs through ten countries (ENS, 1999b). |
| The Ogalalla aquifer (1/5 of U.S. irrigated land) is overdrawn by 12 billion cubic m/yr causing more than two million acres of farmland to be taken out of irrigation (Center for New American Dream, 2000). | In 1995, 29 cities & towns in U.S. corn-belt had herbicides in drinking water that exceeded federal safely levels (Grossman, 1998). | Malaysia sells water to neighboring Singapore and is now demanding an increase in the price of this water (ENN, 2003). |
| China is draining some of its rivers dry and now mining ancient aquifers that take thousands of years to recover (Brown, 1999). | Between 1976-1996, annual rates of harmful algae blooms — leading indicator of health risks for marine animals and people — increased from 74 to 329 (Barker, 1997). | The Mercosul countries of Brazil, Argentina, Uruguay, and Paraguay launched a project for preservation of the Guarani Aquifer that serves all four countries (Muggiati, 2003). |
| Africa's Lake Chad has shrunk from a surface area of 25,000 sq km in 1960 to only 2,000 sq km today (GreenBiz.com, 2003). | Aging infrastructure, source water pollution and outdated treatment technology increase human health risks in 19 US cities (ENS, 2003). | Canada and the U.S. signed a treaty approximately 10 years ago that states no water can be removed from the Great Lakes basin (ENS, 1999a). |
| Mexico City is sinking as residents pump water beneath them -- elevated train tracks, built flat in the 1960s, look like roller coasters now (Center for New American Dream, 2000). | Mass fish kills and disease outbreaks went from nearly unheard of before 1973 to almost 140 events in 1996 (Borenstein, 1998). | Mexico and the U.S. have a long-standing treaty for maintaining water flow in the Colorado River (Stevenson, 2003). |
| One-fifth of the world's freshwater fish -- 2,000 of the 10,000 species identified so far -- are endangered, vulnerable, or extinct (GreenBiz.com, 2003). | Stranding of whales, dolphins, and porpoises linked to poor oceanic environmental conditions jumped from nearly zero in 1972 to almost 1,300 in 1994 (Borenstein, 1998). | Along the Missouri River, there is conflict among navigation, power generation, and environmental concerns (Quaid, 2003). |
| Globally the world has lost half of its wetlands, mostly in the last 50 years (Wilson and Yost, 2001). | | Maryland is in control of Virginia's water destiny (IATP, 2003). |
| Two of every 3 persons could live in water-stressed conditions by the year 2025 (GreenBiz.com, 2003). | | |

## 2.2 How To Act Sustainably

Society consistently faces issues related to economy, environment, and fairness among people. Each of these human concerns is in some way impacted by the forces that drive the natural world. However, development models intended to tackle societal problems have traditionally taken a piecemeal, singular approach, addressing issues of economics, environment, or social health, sometimes in isolation from one another (Flint and Danner 2001). For example, socio-economic systems often become caught up in the adversarial “economy versus environment” debate and begin operating in a linear direction: taking resources from the Earth, making them into products, and throwing them away to produce large amounts of waste (take-make-waste). This process leads to communities being unsustainable. Sustainable development is the centerpiece and key to water resource quantity and quality, as well as national security, economic health, and societal well-being. The word ***sustainability*** implies the ability to support life, to comfort, and to nourish. For all of human history, the Earth has sustained human beings by providing food, water, air, and shelter. ***Sustainable*** also means continuing without lessening (Flint et al. 2002). ***Development*** means improving or bringing to a more advanced state, such as in our economy. Thus, ***sustainable development*** can mean working to improve human’s productive power without damaging or undermining society or the environment—that is, *progressive socio-economic betterment without growing beyond ecological carrying capacity: achieving human well-being without exceeding the Earth’s twin capacities for natural resource regeneration and waste absorption* (Flint 2003). By acting under the principles of sustainable development, our economic desires/demands become accountable both to an ecological imperative to protect the ecosphere and to a social equity imperative to create equal access to resources and minimize human suffering. These requirements are the foundation of sustainable development as represented by the three-circle model (principle elements) sustainability in Figure 1.

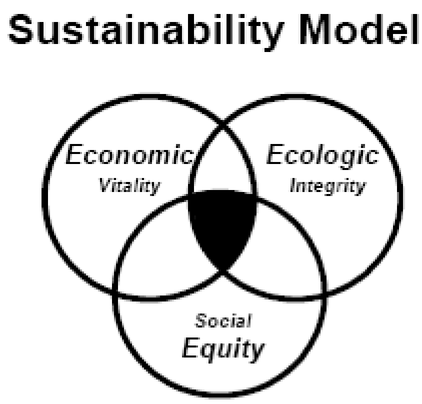



*Figure 1: This conceptual model of sustainable development illustrate the relationship among economic, ecologic, and social issues in decision-making. The black overlap of the three circles represents the nexus of connection among issues.*

## 2.3 Water As A Factor Of National Security

National and international security challenges have shifted since the end of the cold war. Scarcity of arable land, water, and other basic resources is recognized as a critical component of regional security in many areas around the world. Water resources and the associated supply, treatment, and distribution infrastructures are important elements of national security and face a spectrum of threats. [T]he nation is so dependent on our [water] infrastructures that we must view them through a national security lens. (Sandia National Laboratories 2003) The point is that water resources security and sustainability should be thought of in tandem. Water that is safe from terrorist attack but either vulnerable to contamination from industrial, agricultural, or domestic pollutants or is unavailable due to misuse or mismanagement is equally a threat to public health and safety.

## 2.4 Management at the Community Level

The quest for security of water systems, however, may undermine the potential for community-level water resources sustainability, if it is premised on limiting information and decision-making authority over water resources to authorized personnel._Community-based sustainable water resources management is about balancing economic and social desired uses of water resources while preserving sufficient water quality and quantity for natural ecosystem processes (Roseland 1996). This statement is simple enough, and it builds on the principles outlined by Krantz, et al. 1997 (this volume) in their discussion of a conceptual framework for water resources sustainability. Balancing economic and social desired uses of water implies not only weighing human and environmental needs but also balancing the water needs for economic and other purposes among different social groups. In other words, sustainability must involve equitable and just distribution of water resources as well as the costs of securing those resources. Simply put, when groups in society are denied access to needed water supplies, the situation is not sustainable (Roseland 1996) participate in decision making about how water is to be allocated and treated. Centralized government authorities, charged with managing these resources, often carried out the development of water resources from the late 1800s through the 1970s. From mismanagement of water resources in regulated waterways of the western United States to failing irrigation systems in Pakistan, there is sufficient evidence that top-down management approaches have failed to ensure water sustainability (Postel 1992).

Through the 1980s and 1990s, an increasing body of literature has demonstrated the need for public participation and multi-stakeholder approaches to water management (Ostrom 1996). Between 1970 and 2000, the proportion of people in developing countries that have access to potable water has increased from 30 percent to 80 percent. For sanitation the increase is from 23 to 53 percent (Lomborg 2001). This represents a success story of sustainable development. Nevertheless, the billion or more people still lacking safe drinking water and the two billion or more lacking wastewater services are precisely those who lack sufficient money income needed to generate the effective market demand for water that would make investment in delivery infrastructures profitable.

Scholars of community sustainability use indicators of human, social, built/financial, and natural capital to understand the dynamics of sustainable water resources management at the community level (Flora 2000). Social infrastructure in water resources management involves a combination of human capital and social capital. Human capital refers to skill levels and abilities—such as the average level of education in a given community, or the number of people per 100,000 with cancer. Social capital refers to the networks and trust that exist both within and outside the community, such as the number of organizations, the level of participation in community events or the range and number of community members involved in decision making. It also refers to linkages of community groups to other groups outside the community. A critical distinction should be made between within-group ties (i.e., bonding social capital), which often characterize insular communities or groups, and bridging social capital, where strong networks are established with outside groups or institutions. *Built/financial capital* refers to a community's financial resources and infrastructure—both average income and number of roads into and out of the community. *Natural capital* refers to the natural resources and attributes of the given community—such as forest or fish in a stream (Gasteyer et al. 2002).

Using the conventional approach, wastewaster is directed from homes and businesses into a treatment plant, where it is treated with an aeration or similar system, and released into a neighboring stream or river. Alternatives do exist, however, for enhancing natural capital with a constructed wetland, which may have the benefits of allowing for native grass regeneration, and providing a habitat for other species. It would also be possible to put in a decentralized wastewater treatment program—that would be managed through a system that is social capital intensive. Community institutions are established to monitor septic performance throughout town, and educational campaigns ensure that homeowners and renters understand the responsibilities of septic system management. An example is the small community of Spring Hill, Minnesota, where the community worked with an intermediary NGO to get the approval from the state clean water regulator and funding from the Federal government for a constructed wetland to manage a wastewater issue. The program for monitoring the wetland involved multiple community members. More importantly, the wetland used native plants to treat the wastewater, which has attracted visitors from throughout the country to admire the system, increasing community pride (Miersch 2001).

## 2.5 Sustainable Water Resource Development

The main question is how to integrate the development in management and planning, sustainability concepts, with the growing number of disciplinary qualitative and quantitative models, and the advances in information technology. How to achieve sustainable ways of making use of resources in particular, sharing limited water resources, and how to implement adaptive co-management concept. According to Hallding (2001) sustainable solutions can build on:

- Understanding of the sources the conflicts, including their natural, technical, institutional, social and cultural aspects.
- Participation of all the related stakeholders in the process, first to arrive at common understanding of the problem and to share as far as possible a vision about the future and ideas about the path to sustainable solutions.

- Examining the social, environmental and economic contests of the conflict, in order to assess different policy options to make the best use of limited water resources.

This may include regulation, financial sanctions and economic incentives, and increasing public awareness and participation, information dissemination and support for possible institutional change.

- Finally an organization to pursue the co-operation, a means of monitoring achievement, and implementation plans

# CHAPTER THREE

## Historical Background of Heng Shui City

Heng shui city lies South East of Hebei province, located between 115º10′E～116º34′E, 37º03′N～38º23′N, on a level plain similar to a rhombus shape, it is approximately 125.25km N.S In length， and approx. 98.13km E.W in width, hence it cover an area of about 8815km$^2$。Wei channel and the south lies respectively in the east and southeast, and beyond it is the Shandong province, bounded by a common mountain towards the east, it northeast area in border by Can Zhou city, southwest plain adjoining Xing Tai, west plain and north plain border by Shi Jia Zhuang city respectively, adjacent is Bao Ding city the former capital of Hebei. The city population as of 1998 is estimated as 4.1226 million, among which the population is made up of 3.445 and 0.68 million farming and non farming respectively, the city GDP stands at 2.663 million Yuan and it plantation agricultural land is estimated as 582598 Ha.


Figure 3.1: Showing the area of China and Hebei relative position

The city is bounded by 9 Rivers that runs across it, including these 3 big parallel rivers namely Fu Yang River, New Fu Yang River and Fu Dong (East) Pai River, which pass centrally from the southwest to the northeast, the Fu Xi (west) and Fu Dong (east) rivers divide Heng Shui into two equal part. Hu Tuo River flows from the west to east passing through the north of Fu Xi, also is Suo Lu River～Lao Yan River, Qing Liang River, Jiang Jiang River flowing from the southwest to north east running across the Fu Dong River, Wei Channel～South Channel flows by the eastern border of Heng Shui city. Apart from the Jiang Jiang River, which originates from the Heng Shui municipality, other river flow through the city, New Fu Yang and Fu Dong Yang River is all artificial river created after the establishment of the PRC. Wei channel and the South channel is both artificial channel created 1300 years ago during the Sui Dynasty. The flow of the Huang River and the Zhuang River through Heng Shui city subsequently brings about increase productivity in agriculture, industries and standard of living. Although it frequent flooding is not without negative effect. Since 1956s to the 1980s, many rivers have been created including Fu New River, as well as construction of water conservation project, which in order word have reduced flooding to the barest minimum. Heng Shui region experiences an annual rainfall of 522.5mm which is too far from meeting the water needs of the city for industrial and agricultural purposes, the alternative source of water resource, which is fresh-water is also found in little quantity amounting to only about 7.34million $m^3$

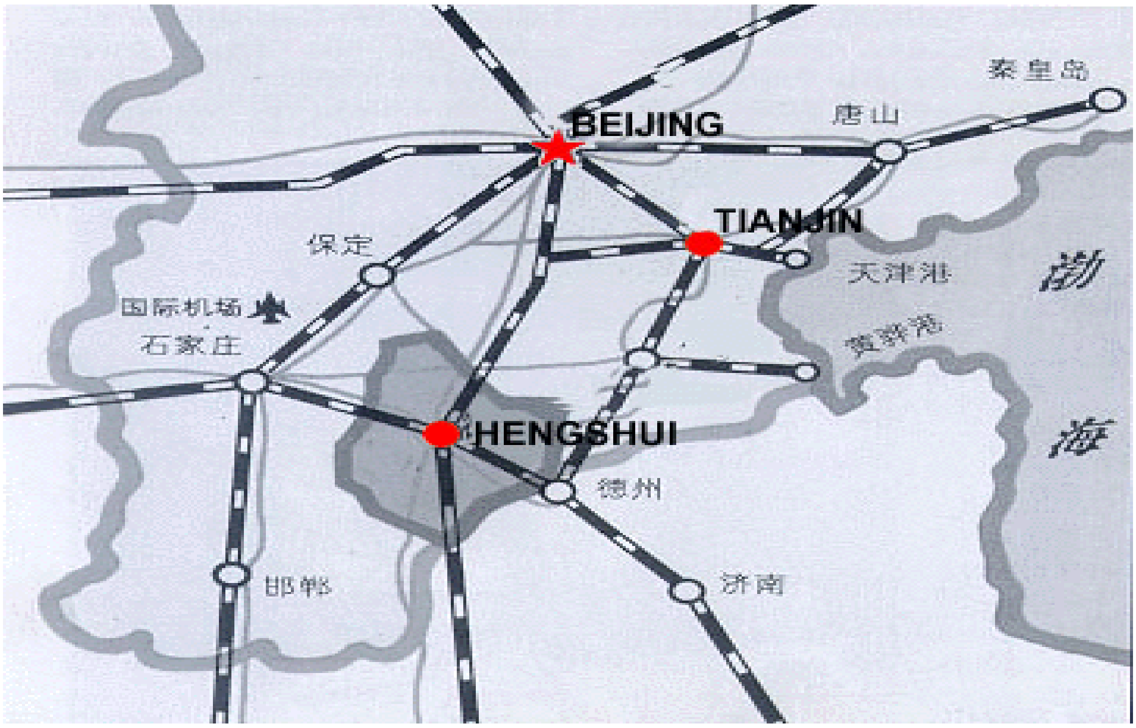



Figure 3.2: Showing the Sketch area of Hebei Province and the relative position of Heng Shui City

## 3.1 Natural Environment

Heng Shui City land generally, is strip shape in nature, marshy, low land and widely dune dispersing, covering about 75km$^2$ of the Heng Shui Lake in Hebei municipality; this lake is the first batch wetland and bird natural protection area. It is a temperate region characterizing terrestrial monsoon climate, having four distinct seasons and sufficient sunlight, it winter is dry and cold, summer hot and raining, spring and autumn are generally cold and most suitable for agriculture and human development.

### 3.1.1 Relief

Terrain is generally flat, formed from the Yellow River, Zhuang River, Hu Tuo River, it has a level plain extending from the southwest to the northeast, and north part is level from the northwest to southeast because of the influence of Hu Tuo River. South part level plain emerges from the southeast to the northwest, as a result of the influence of the Yellow river. The sea level stands at 12.6 to 30.0m, topography gradient in the west of Fu Yang River and that in the east of the Fu River ranges from 1:4000—1:6000 and 1:6000—1:8000 respectively. This gradient is relatively low and thus making it relatively difficult for drainage flow, which makes exploitation and exhaustion of the underground water very eminent, subsequently resulting in drastic declining of the ground water annually. Also high salinity occurs because of it intense use for irrigation purposes, and therefore causing erosion. The frequent changes and over flooding of the Yellow River and other rivers, causes deposit to be widely distributed in Heng Shui region and the lake itself, the influence of the wind force and human activities makes the level terrain vary greatly from about 30-50cm and could reach a record high of 1.0m..

The artificial creation of the South channel, Fu Yang, Hu Tuo, New Fu Yang, and other rivers such as the Jiang Jiang, Qing Liang, Suo Lu have in no small measure serve as control measures for flooding and this have effectively influenced water conserving environment greatly. The different rate of adsorption and infiltration of water and its pollutant in Heng Shui region is as a result of the different kind of soil types present. Basic water constructions for agricultural conservation were carried out for purpose of irrigation and drainage; rivers created for this purpose are the Shi Jin channel, Wei Qian channel, this channel intercept and impose influence on the redistribution of the water and its pollutant.

### 3.1.2 Climate

Temperate region of terrestrial monsoon climate, the climatic dryness ranges from 1.23 $^{o}$C—1.37$^{o}$C of the continent 65.6%, made up of 4 distinct seasons, characterizing of long winter and summer and, short spring and autumn. Spring is dry and windy, summer hot and raining, autumn is cool and winter dry and cold with little snow, it average annual temperature is 12.6 $^{o}$C with January been the coldest having a temperature of about -4 $^{o}$C, the lowest temperature ever recorded at this period was -26 $^{o}$C, July is known the hottest month with average temperature of 26.6 $^{o}$C, and the highest temperature ever recorded for this period was 41.5 $^{o}$C. Heng Shui city non frost period is totally about 191days, soil frost between mid November to mid March, annual precipitation is about 522.5mm, though it is not evenly distributed with eastern part having more rainfall than the central and the western part, e.g of the central part are Ji Zhuo and Shen Zhuo cities having annual rainfall of 501mm, east part of Ji county, Fu county, were 557.5mm, while the west is 21.6mm, in general, the total annual rainfall is 185 million $m^3$ which also varies yearly, in 1964, the annual average rainfall was 950.9mm, and was declared as abundant year of rainfall while 1965 and 1997 was the lowest ever recorded, having 283.2mm and 271.2mm respectively. See table 3-1 for the monthly distribution of rainfall.

Table 3-1 Heng shui city average monthly precipitation quantity distribution

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ppt | 0.5 | 1.0 | 3.0 | 4.0 | 14.5 | 59.0 | 56.5 | 248.5 | 73.5 | 17.5 | 8.0 | 14.0 | 500.0 |
| % | 0.1 | 0.2 | 0.6 | 0.8 | 2.9 | 11.8 | 11.3 | 49.7 | 14.7 | 3.5 | 1.6 | 2.8 | |

The city gross annual average sun radiation is 125.329therm/$cm^2$, with an average of 15.935therm/$cm^2$ in 5 months period. February had the least average of 7.717therm/$cm^2$, farm production thrive very well during the months of June and September when the sun radiation is at it peak, averaging 49.457therm/$cm^2$ accounting for 39.4% of the year output. Annual sunlight time was 2609.9hours, the highest 5 months periods was 279.9hours, and the least 2 months period amounting to 170.4hours, the annual sunlight radiation was calculated as 59%. Table 3-2 shows the abundance distribution of sunlight.

Table 3-2 Heng Shui yearly average monthly sun radiations

| Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sun/hour | 184.6 | 174.4 | 222.7 | 232.0 | 279.9 | 265.2 | 219.1 | 221.0 | 222.3 | 215.8 | 177.4 | 178.6 | 2593 |
| % | 61 | 58 | 61 | 59 | 64 | 60 | 49 | 53 | 60 | 63 | 59 | 60 | |

*Source; River and Hydrology*

In the city of Heng Shui only two out of the nine rivers and channels are very long, they are Hu Tuo and the South channel while the rest are relatively short and rapid flowing, although due to the flatness of the Heng Shui Plain, the area is susceptible to flooding especially after heavy rainfall, high power river flow is more visible during the raining season period of July to September for each year.

There are 4 rivers in the Hei Long Gang area, which are located between South China and the Fu Yang River, these river are Jiang Jiang, Suo Lu, Fu Dong Pai and the Qing Yang River. From research work and data for the years 1956-1993, the average depth of flow was 19.1mm, whereas the annual 50% and 75% certified water precipitation were 10.5mm and 3.5mm respectively, the distribution of water at the top floor is more pronounced than the precipitation, while the occurrence of flow is between July and August.

The main irrigation channel of Heng Shui main trunk, are Shi Jin channel, which collect water from the Huang Bi Zhuan reseviour, the water collected passes through Shan Zhuo city to central Wu Qian county, the central irrigation area found below the Shi Jin central channel and Qi Nan central channel reaches a total of 1.74 million(unit area, Chinese scale), Wei Qian Channel collect water from Wei Wu Yun river, it passes through the central Zao Qian county to Heng Shui lake, on the right into Qi Nan for Gu Cheng county, Jing county, Zao Cheng county, Fu Cheng county and Wu Yi county. Each year the water imported into Heng Shui Lake was about 52 to 187 million $m^3$, and this water is mainly use for aquatic breeding and arable irrigation. Wu Qian channel could import water from Wei Yun River only in the rainy or post rainy season because of high water table. From 1994, Qi Nan River works serve as the main channel in importing water from the Yellow River. The total amount of imported water into Hebei province was 500 million $m^3$, among which *150 million $m^3$ was allocated to Heng Shui City,* by the end of year 2000, the total amount of Yellow River water imported to *Heng Shui city reaches 480 million $m^3$,* which subsequently leads to community and economy development and also increase the living standard in Heng Shui city and the nation in general.

### 3.1.3 Hydrological and Geological Regions

**-Hydrological and Geological Region Form by River Charge (Central Hebei Concave Region)**

The influential ranges of the Hu Tuo River include An Ping, Rao Yang County and Shen Zhuo City, the fourth strata deposit is the largest, characterize with thick and continuous sand layer. It sand granular is relatively coarse and it has good ability in retaining water, the thickness of it aquifer is between 100-150m while some part could be as high as 200m, lithology mainly consist of middle/small or middle coarse granule, sand layer average rate of water infiltration is about 0.3-0.6T/h.m. The west is made of completely fresh water region while south eastern part to a depth of 50-70m are found some layer of salty water.

**-Hydrological and Geological Region Form by River Charge (Cao Zhuo Convex Region)**

The influential range of the Fu Yang River include Ji Zhuo city, Zao Qian county, Tao Cheng district, Wu Yi county, Fu Cheng county, the thickness of it fourth strata is approximately 460m, water is distributed abundantly in it strip shape layer to a thickness of about 70-120m. Lithology mainly consist of small/middle and some small and middle sand granule which have poor ability in retaining water, it average rate of water infiltration is between 0.1-0.3T/h.m, just above it, is widely distributed bulk of salt water to a thickness of 50-130m.

**-Hydrological and Geological Region Form by River Charge (Cao Zhuo Convex Region)**

The influential range of South China range include the large stripe region in the eastern part of Ji and Gu county, the thickness of it fourth strata is about 55m with abundant water, it thin layer is made of 40-70m thickness. Lithology mainly consist of very small set of granule, sometime including middle/small or middle coarse granule, it have poor ability to retain water and it rate of water infiltration is 0.1-0.1T/h.m, among which the thickness of it sandy water body varies from 100-200m.

### 3.1.4 Classification of Aquifer

The upward classification of the four aquifers corresponds to the classification of the four strata.

**1st Aquifer group ($Q_4$):** Charge by the river and deposit of the wetland or the marshy land, consisting of loose material such as sand, mud, 50-70m thicknesses. The lithology of aquifer mainly consists of small size granule and infiltration is less than 0.3T/h.m. Apart from the fresh water in the northwest part, other part are salt water body, the water stripe shape is 10-30m and in special case 50-70m thickness. Swallow fresh water deposit layer are disperse widely in four counties namely Fu Cheng, Zao Qian, Jin and Gu Cheng located in the eastern part of Heng Shui city, whereas the central part is disperse scarcely with a very thin thickness, the aquifers group is typically superficial in nature. At present only it swallow water are been extracted and exploited for use.

**2nd Aquifer group ($Q_3$):** Formed mainly by river charge and partly by flooding deposit in the northwest, and some part formed by the wetland, the material here is mainly loose soil such as sand and mud, bottom depth varies from 170-250m, thickness of 120-180m. Lithology of the aquifer mainly consist of small size of granule, it rate of water infiltration is 0.1-0.3T/h.m. This aquifer groups belong to the confined water, besides, the salty water that is found in the upper eastern part, others are completely fresh water, mineralization rate is less than 1g/L, at present, the aquifer is widely exploited towards the north of the Fu Yang River.

**3rd Aquifer group ($Q_2$):** Formed by the river charge, flooding and partly lake deposit, the material are virtually loose such as sand and mud, the aquifer consist of small middle size or middle size granule, the rate of water infiltration in the sand layer is 0.2-0.3T/h.m. This region belongs to the confined water, mineralization degree is less than 1g/L, it bottom depth is put as 350-450m and it thickness is between 180-200m. At present it deep fresh water is being exploited.

**4th Aquifer group ($Q_1$):** Formed mainly by river and lake deposition, the northern part is partly characterize by the formation of flood charging and deposition, the bottom depth ranges from 450-600m and above, thickness of 100-400m, aquifer layer mainly consist of small or middle size granule, this aquifer group possess smooth but poor sandy layer, the rate of water infiltration is 0.2T/h.m. Belonging to the confined water, mineralization degree is less than 1g/L; the stickiness of the clayey layer is thick and distributed widely. Presently only small amount of the aquifer is been extracted and exploited for use.

### 3.1.5 Regional Underground Recharge, Runoff and Drainage Condition

In Heng Shui city, especially in the fourth aquifer group, there are deep strata (confined water) and shallow strata (ground water layer and minor confined water), the condition of runoff, recharge and drainage is quite different.

***-Shallow Layer Water:*** Comprises the first aquifer group which belong to the ground water and minor confined water zone, because of it shallow location, there is no continuous thick confining bed, so that the shallow layer can receive precipitation recharge directly. It recharging condition is better than the deep fresh water layer. The main recharging source is from precipitation. It average annual precipitation comprehensive amount for the city is 678 million $m^3$, accounting for 82% of the total recharging amount. The recharged by the other water body are (River channels 21 million $m^3$, irrigation channel 24 million $m^3$, irrigation by channel water 17 million $m^3$ as well as irrigation from wells 60 million $m^3$) totaling 122 million $m^3$ representing 18% of the total recharged amount group. Water evaporation and human exploitation is the major aspect of drainage, the total by human exploitation for many years reaches 432 million $m^3$, also because of the small size of it granule in the aquifer layer, small hydrolic angle and runoff, and hence groundwater cycle alternating function is very slow. The salty water layer which varies from 10s to 100s metres, settle above the deep confined water layer, thereby making the recharging condition poor and poorer, also the influence in the alteration of the deep layer is evident in the long run because of human exploitation. Presently it is recharge by stream crossing interchange. Human exploitation still remain the main actor for it drainage.

### 3.1.6 Trend/ Dynamic of Irrigation.

**-Shallow Layer Underground Layer:** The alteration of shallow layer ground water was influence mainly by meteorology and exploitation in various counties and cities, underground level varies greatly for example in the dry years, the water level is usually at approximately 5m and shallow fresh water layer with salty water region varies from 3–5m, atmost 6.37m, the charging range of the minor salty water layer is between 1–2m. Completely, in the north part, fresh water is located between 12–16m and atmost 20m, while in the north of Fu Cheng and Jin County is the salt water region, and where there are shallow fresh water development, the depth is between 8–12m. The region of Gu Cheng along the Wei River and the Zao Cheng county along the line of Tanglin—Zhangmi, the depth is from 10–16m, at the other district, the depth is 4–8 m. In the Tao Cheng district north of the Ji Zhuo city and most part of the Shen Zhuo city where there is minor salty distribution, the depth is between 2–4 m. The location of the completely fresh water region is beyond the limit of the underground water evaporation, thus making it main influential factor as precipitation, recharging and major range of human exploitation. The trend of water level is usually low at the beginning of the year when there is no exploitation, this underground water rises slowly and it reaches it peak in march, though when agricultural irrigation begins, the water level decreases accordingly, it reaches it minimum in the months of May/June, but when the rainy season begin and human exploitation reduces, the water level reverse it trend upwards. The intense irrigation, less rain in autumn and winter causes the water level to decrease until the end of the year when the water began to rise slowly. The charging process for the year is double crest and trough.

**-Shallow Layer and Ground Water:** Influence only by precipitation and evaporation and reach it lowest water level at mid/ late June, under the influence of evaporation. After the precipitation recharge, the water rises and reaches it peak in September, afterwhich it decline gradually, the charging process for the year is single crest and trough.

**-Deep Layer ground Water:** The deep-water layer is confined water, before the exploitation, the flowing direction is from the southwest to the northeast. The charging trend follow this trend; deep layer ground water is directly influence by precipitation, the charging condition of the underground water present at single crest, from late February the water level start to decline because of spring irrigation, this continue until late June, when the rainy season begins, irrigation seizes, the underground water level begins to rise, but during the mid September because of autumn irrigation the water level decrease. From mid October when wheat plantation ends, the water level continues to rise towards the end of the year. This is the time the depth water reaches it maximum. After the year 1970, because of the large scale of water exploitation, it form large areas of the falling tunnel, change it natural flowing direction, in most area, it confluence at the middle of the tunnel. In recent years, because of the dry climate, the month of exploitation is much more than that of recharge. The water level declines annually and in any case the water will only rise in a situation where the recharging amount is greater than the exploitation amount. Subsequently, the ground water level increase along the year and the charging trends present as a wave shape declining.

## 3.2 Water Resource Status

Heng Shui major water resources are Surface water, Groundwater and Imported water; see the table 3.3 statistics below. According to Heng Shui city, the period between 1957 and 1998, 42 years water resource calculated quantity data, the city have only produced a total annual quantity of 491 million $m^3$, which is just averagely 120 $m^3$ per person, accounting for only 48% of the city total water resource, which is not sufficient as a country average.

Table 3-3 Heng Shui Water Resource Composition Statistic Table Unit:$10^4 m^3$

| Year | Surface Water | | Ground Water | | Imported Water | | Total Water Quantity |
|---|---|---|---|---|---|---|---|
| | Self Produced Water | Natural Imported water | 〈2g/l〉 | 2～3g/l | Induce Yellow River | Induce Shi Jin Irrigation Channel | |
| 1993 | 2857.7 | 16280 | 28613.3 | 25659.2 | 1860 | 10954 | 60565 |
| 1994 | 7969 | 9895.9 | 29810.4 | 31424.8 | 12469.1 | 15778 | 75922.4 |
| 1995 | 2055.6 | 38595 | 43448 | 39065.3 | 7571 | 17384.2 | 109053.8 |
| 1996 | 6286 | 339924 | 67996.5 | 52105.1 | 0 | 24455.6 | 438662.1 |
| 1997 | 0 | 18963.5 | 14800.4 | 16223 | 8382.2 | 29821 | 71967.1 |
| 1998 | 1561.5 | 5128.1 | 28191 | 27932.8 | 11865.7 | 41231.8 | 87978.1 |
| 1999 | 0 | 3220.3 | 15815.1 | 14751.6 | 7861.3 | 15871 | 42767.7 |
| 2000 | 11207.3 | 116936.8 | 45442.4 | 45727.1 | 8000 | 21700.3 | 203286.8 |
| 2001 | 3169.8 | 40745 | 36918 | 34503.7 | 8000 | 21342.9 | 110175.7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2002 | 171.3 | 38286.8 | 26611.4 | 24675.3 | 8000 | 11546.2 | 84615.7 |
| 2003 | 12660.6 | 129084.9 | 59231.7 | 52202.6 | 8042 | 9166.1 | 218185.3 |

## 3.3 Social Environment:

Heng Shui can boost of a convenient traffic, Shi Ji Zhuang--- De Zhao railway that run across the whole area. Heng Shui city is the connecting point between Beijing----Shanghai railroad in the east and it also connect Beijing ----Guangzhou in the west. Beijing----Hongkong runs across the north to south, which makes Heng Shui city the second largest railway traffic hinge in Hebei Province. The total length of the motor way is 8292.4 km, and it density is 0.94km/km$^2$, this web of road spread outwardly from the city of Heng Shui municipality, these convenient traffic facilitate development of industry and agriculture. In 1995, the GDP in Heng Shui reached 26.624 billion yuan and the GDP per capita was 6476 yuan, this really meets the advance goal of double increment.

As of 2002, the population of Heng Shui city has reached 4.108 million of which 3.374 and 0.734 million are farming and non-farming population respectively. The city GDP increase to 351 billion yuan, an increase of 10.2 % to that of the previous year, while per capita GDP for individual stands at 8548 yuan, also an increase of 10.2%, the great increase of 19 billion yuan accounting for 54.8% of the city GDP of the industrial sector brought about increase standard of living and stabilization growth in it economy, by the year 2002, the administrative per person earning was 6081 yuan and spending was 4463.6 yuan, an increase of 14.8%; while the whole city ENGEL coefficient was 31.7%, less 0.3 of the previous year.

Presently, the city is experiencing economy sustainability, accelerated development, health development; increase in it integrated economic strength, speedy increase in production structure rectification e.t.c. The table below shows in relative to population, the large increase in economic strength of Tao Cheng, Ji Zhuo, Shen Zhuo, Wu Yi, and Zao Qian county, this region GDP accounts for the whole city GDP of 58.44% see table 3-4 below

## 3.4 Agriculture, Forestry and Fishery

By the end of 1998, the farming population in Heng Shui has reach 3.446 million accounted for 83%. The Mechanized well dug in this city amounted to 62,503 units and the effective irrigation area was then put to 0.4395 million Ha accounting for 75.4% of the total farmland. The agricultural machinery power consumed 5.0069 million kilowatt, the total electricity used.

The agro-industry in Heng Shui has earned it preliminary stage of development, has strong characteristics structure of which it present 11 leading industries, foodstuffs, cottons, plants, vegetables, fruits, cattle, sheep, pigs, livestock, aquatic products and special breed. The industries had laid a stable foundation for modern agriculture in Heng Shui, the income per capita per farmer reached 2,366 yuan. The establishment of scientific technique also resulting in the increase usage of chemical pesticide and fertilizer, by the year 1995, the fertilizer used was already 0.9186 million tons, and that of pesticide was 6983 tons, this has play an irreplaceable role on the increment in agriculture, forestry, cattle rearing, fishery production, though not without effect of pollution. This happen in a situation where part of these chemical are absorbed by plant, entering underground water as a result of filtration of irrigation water and rainfall runoff, thereby causing increase pollution density in river bed when carried by river runoff, the above clearly demonstrate a nonpoint source agricultural pollution. In Heng Shui water is scarce and as such farm production are mostly in medium or lower productivity. The agriculture production level are far below that of the planned area of Hebei province and the ecological system is vulnerable and as such have low resistance to natural disaster such as drought and flooding

## 3.5 Industry and Rural Enterprises

Heng Shui has 6 main supporting industries, chemical, construction material, fabric, medical, food and machinery industry, it also has some auxillary industries such as heating, silk grain, fur and skin, coffin safe, glassy steel and motor fitting industries and agricultural machinery industries. In 1998, there are 29,879 industrial enterprises which has accrued a total income of 46.295 billion yuan, this is 27 times compare to that of the year 1978, industrial increment of 12.65 billion yuan, 8.3 times that of 1978. Industrial production accounted for 53.3% of the Heng Shui GDP and become the main support of it economy. The emergence of large enterprises such as Chun Feng, Xu Ri, An Ping silk Screen, Heng Shui Lao Bai, Meng Niu, Yuan Da, Ji Heng Industry groups, have created products that were being patronize all over the country, which have steadily enter the international market, though in Heng Shui, the 497 types of it enterprise are middle size and relatively small, producing an income of about 4 million yuan.

The existence of large quantity of rural enterprises in Heng Shui and the low level of technology has cause a great deal of harm to water, atmosphere and agricultural environment. These industrial waste exhaustion reaches 20.28 million tons, the waste water along with 0.3 billion tons waste water from the upper river of other cities such as Han Dan, Xing Tai, Shi Jia Zhuang were piped into the Fu Yang, Hu Tuo, River, South channel which makes the river black and bringing out offensive odour, also resulting in the death of trees along the river, more mosquitoes, spiral shell and extinction of aquatics life, deteriorating of soil quality, and badly affecting the quality of life.

## 3.6 Postal Communication, Education and Sanitation:

Heng Shui is a rapidly developing district and the post and telecommunication develop rapidly. By the end of 1998, postal size income has accrued a total amount of 98.1052 million yuan and that of telecommunication site reached 1.032 billion yuan. The telephone exchange reached 340,000units and the simulated digital Mobil band channel reaches 1521units, long trunk government telephone service reaches 25,400 lines, also the advanced digital programme exchange microwave light sensitive telecommunication was also established, telecommunication production, enterprises enforcement and management e.t.c achieved the goal of modern management which is the characterized by computer application, helping in the steady enforcement of developing strategy " sense in education promote city".

In the year 1995, Heng Shui established early stage compulsory education, by 1998, the 10 out of the 11 counties have established the 9 year early compulsory early education, the population who received this education reaches 94.9%, vocational technology education, adult education developed steadily, by the turn of 1998, the city have engaged the services of 44,000 staff in all level of schools.

With societal economy development, the total better health level of the population rose greatly, by comparison between 1998 and 1949, mortality rate declines from 9.8‰ to 4.02‰ and the average life expectancy rises from 35 years to 70 years, "everyone is strong enough to engage in agricultural and industrial production with great zeal and work towards the betterment of living standard." It is the popular saying of Chinese leader aimed at energizing it labour force to be productive.

Alhough it remained a fact that the source of drinking water in Heng Shui is mainly deep layer and ground water. The frequent inflow of fluorine into this water bodies have exceeded the life drinking water standard of 1.0mg/L, hence in the attempt of the population consuming this bad fluorine water which accounted for 51.3%, of the entire population, have cause great deal of health implication such as spotted teeth symptoms and other fluorine related diseases, which is endemic in nature.

While the water resources scarcity is not only limited to Heng Shui City, it is a general phenomenon that plaque the whole country of China. It is expected that before the year 2010 it will develop at an annual economic growth rate of 8-10 percent. Meanwhile the urbanization rate will increase from 21 percent to 35 percent. The water demand of the whole country will increase from 5,200 hundred million cubic meters to 7,200 hundred million cubic meters. Among the newly increased water demand, two thirds will be the cities' increasing demand. According to the statistics of the 570 cities nationally it is estimated that the daily water shortage has been already more than 15 million cubic meters. More than 260 cities face water shortage with 124 in acute distress of water resources (Heng Shui Inclusive). Water scarcity has already had impact on the normal life of more than 40 million urban residents and at an estimated cost of U$24 billion in lost economic output each year. If this trend of water shortage continues it will no doubt become the important constraint for China's economic development and hinder the people's living standard improvement.(Hu Zhong Ping.pdf Feb 2003).

While agricultural use is still the dominant use by far, its share of water supply has decreased, while domestic and industrial water uses have been increasing rapidly. Domestic water consumption in urban areas has been rising in both absolute and relative terms due to a combination of (a) increased urbanization, (b) increased per capita consumption of urban residents, and (c) increased water use efficiency within the industrial sector. Use as a proportion of the water available is well above the national average in the North China.

The solution to solve the water shortage in North China and the dry-up of the Huanghe River should be based on developing water saving and making full and rational use of local water resource, and the overall consideration given to the rational deployment of water resource of four large river basins (Changjiang River, and Huanghe-Huaihe-Haihe River Basin). Meanwhile, construction of the South-to North Water Transfer Project should only be use as a supplement.

## 3.7 Water Resources and Exploitation Utilization in Heng Shui City.

Heng Shui city water total resource was 735 million $m^3$ (other include shallow fresh water which account for 618 million $m^3$, natural production flow of 195 million $m^3$, recycle water 78 million $m^3$), Human average usage was 185 $m^3$ for the years (1956-1993), just only 383$m^3$ (48%) of the provincial average and 3338 $m^3$ (8.3%) of the China's. and the world 2238 $m^3$ (2%), but taking 1956-1997 water resource analysis, Heng Shui City annual average can only boost of 491 million $m^3$, serving a population of 4.13 million people, which implies that, per person average water resource is 120 $m^3$, this is declared as the province with the most lacked water resource. Infact annual water supply quantity is between 1.4-1.7 billion $m^3$, while water demand is twice the supply, hence making annual average water exploitation to increase. At the same time, Heng Shui city is a natural disaster prone area, as drought, flooding, and outstandingly severe arid region. Basically it is always true that for every ten years, nine years is drought period or sometime ten years ten years drought, from 1980 to 1998 period, except for the abundant year, the rest are severe drought.

From 1989 to 1998, the city annual average precipitation stand at only 480mm, compare with it previous 10 years period, which have reduced by 66m averages. While many years annual average evaporation quantity is 1200 mm which are approximately 2.5 time that of precipitation.

In the scope of this area, though there are the tendencies to induce other water bodies to the city channel, this was also restricted to some extend because of the ascending flow of the reserviour storage tank; thus making the annual average water import to only 141 million $m^3$. Shi Jin channel is the only channel that has some level of stability, it water importation is in the springtime i.e March to April, having an annual average water import of 239 million $m^3$. In 1994, the city started the construction of inducting Yellow River to Hebei project, so that in every winter, the project will compliment surface water, winter irrigation, and provisional drinking water usage as well as Heng Shui electro industrial water usage, it yearly estimated import water quantity amounts to 150 million $m^3$.

Recently, owning to the scarcity of surface water, ground water resource is the only reliable source. Deep fresh water layer exploitation quantity reaches 243 million $m^3$; in fact annual exploitation reaches 400-800 million $m^3$. By 1998, the deep-water exploitation has reached 908 million $m^3$, greatly exceeding water resource replenishment ability, resulting in water table continual decline. By the year 1972, the funnel (Ji, Zao, Heng) size area was only 2686 $km^2$, and has enlarged in the year 1998 to 8201$km^2$, occupying 93%. This funnel center is buried underground to a depth of 15.92m which had now increased to 81.04m. 1998, the whole city deep layer groundwater average burying depth was 49.46m, 3.30m deeper than that of 1997. Funnel areas continued to enlarge as well as the continual increment of it depth limit. Because of the poor quality of the swallow groundwater layer, it makes to certain extent the reduction in it exploitation, yet exceeding the replenishment capacity and not allowing for full maximization.

The results of this water table declining are enormous, causing ground sedimentation, groundwater quality deterioration, salty freshwater boundary declined, cracking, series of environment problem, and difficulties in groundwater exploitation. Hence conservation of this groundwater resource is most imminent

## 3.8 Water Resources

Heng Shui city water resource have three major important aspect, first is the city scope atmospheric precipitation form of surface water resource and ground water resource, secondly, Gang nan, Huang Bi Zhuan through Shi Jin Guan supplies the city west part agricultural water resource and the Shang Dong province mountainous location, Qing Liang Jiang, Wei Qian Qu Yin Huang, Yin Wei water quantity and thirdly, Owning to the ascending converging import scope of surface water resource.

### 3.8.1 Precipitation Amount

**-Administration Diversion Precipitation Amount**

According to the analysis from 1956-1998, the average annual precipitation amount was 522mm, where the eastern part of Gu cheng, Jing and Fu cheng county have large amount of rainfall, western part of Ji zhuo city, Shen zhuo and An ping county have otherwise, the eastern part have 10% precipitation than the west.

The city annual variation is large; the annual variation coefficient ranges 0.3-0.4. Shen zhuo maximum annual precipitation was recorded in the year 1964 (900mm) while it lowest annual precipitation was recorded just the year after the maximum, which is 1965 (165mm), other counties annual maximum and minimum precipitation ratio is relatively large, ranges are from 3-4, for different certification rate. See the table 3-5 and 3-6 below.

Table 3-5 Showing Heng Shui Different Administrative region certified annual precipitation quantity statistics table

| Region | Control Area ($km^2$) | Average value R | Cv | Cs/Cv | Different certify rate ppt qty | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 20% | 50% | 75% | 95% |
| Heng Shui | 8815 | 522.2 | 0.28 | 2 | 651 | 500 | 407 | 300 |
| Tao Cheng | 598 | 502.9 | 0.3 | 2 | 621 | 480 | 390 | 280 |
| Ji zhuo | 918 | 473.1 | 0.28 | 2 | 590 | 460 | 380 | 280 |
| Zao Qian | 894 | 508.2 | 0.3 | 2 | 630 | 506 | 400 | 290 |
| Wu yi | 822 | 507.4 | 0.35 | 2 | 660 | 490 | 390 | 280 |
| Shen Zhuo | 1244 | 493.6 | 0.3 | 2 | 615 | 483 | 386 | 274 |
| Wu qian | 451 | 526.7 | 0.32 | 2.5 | 664.1 | 506 | 400 | 295 |
| Rao yang | 573 | 521.7 | 0.32 | 2 | 667 | 510 | 400 | 290 |
| An ping | 493 | 498.1 | 0.31 | 2 | 629 | 490 | 390 | 275 |
| Gu cheng | 942 | 535.7 | 0.29 | 2 | 673 | 530 | 422 | 299 |
| Jing county | 1183 | 543.4 | 0.28 | 2 | 675 | 533 | 436 | 321 |
| Fu cheng | 697 | 546.1 | 0.32 | 2.5 | 689 | 536 | 421 | 306 |

From the table above, we can see that, the city have a non uniform precipitation distributions, with 70-80% in the rainy season June to September, but most occurs during the months of July/August. See table below.

Table 3-6: Heng Shui annual different certify ppt quantity distribution table unit：mm

| Water annual average | | Monthly Distribution | | | | | | | | | | | | Jul to Sep | Yearly |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | | |
| 20% | Ppt Qty | 0.7 | 7.2 | 10.4 | 58.6 | 31.2 | 45.6 | 335.9 | 111.3 | 31.2 | 7.2 | 11.7 | 0.0 | 524.1 | 651.0 |
| | % | 0.1 | 1.1 | 1.6 | 9.0 | 4.8 | 7.0 | 51.6 | 17.1 | 4.8 | 1.1 | 1.8 | 0.0 | 80.5 | 100.0 |
| 50% | Ppt Qty | 0.5 | 1.0 | 3.0 | 4.0 | 14.5 | 59.0 | 56.5 | 248.5 | 73.5 | 17.5 | 8.0 | 14.0 | 437.0 | 500.0 |
| | % | 0.1 | 0.2 | 0.6 | 0.8 | 2.9 | 11.8 | 11.3 | 49.7 | 14.7 | 3.5 | 1.6 | 2.8 | 87.4 | 100.0 |
| 75% | Ppt Qty | 2.0 | 0.4 | 5.6 | 6.0 | 9.6 | 63.6 | 172.4 | 36.4 | 40.8 | 10.0 | 53.2 | 0.0 | 312.8 | 400.0 |
| | % | 0.5 | 0.1 | 1.4 | 1.5 | 2.4 | 15.9 | 43.1 | 9.1 | 10.2 | 2.5 | 13.3 | 0.0 | 78.2 | 100.0 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95% | Ppt Qty | 1.2 | 0.0 | 0.3 | 29.5 | 3.2 | 12.1 | 90.0 | 46.0 | 11.5 | 64.9 | 31.9 | 4.4 | 159.3 | 295.0 |
| | % | 0.4 | 0.0 | 0.1 | 10.0 | 1.1 | 4.1 | 30.5 | 15.6 | 3.9 | 22.0 | 10.8 | 1.5 | 54.0 | 100.0 |

### 3.8.2 Recent Precipitation Conditions

In 1998, the city of Heng Shui annual average precipitation amount was 407.1mm and total annual precipitation of 3.589 billion $m^3$, 22.1 % less than the average amount recorded in the years 1956-1998. Annual average precipitation greater than 500mm was recorded in the south east including south of Zao cheng, mid and north of Gu cheng, and most part of Jing county. The maximum of 646.9mm was recorded in Bai li zhuang in Jing county, the precipitation is relatively small in the north west part of Heng Shui city, while in the west of Tao cheng, An ping county, most part of Rao yang county, the precipitation is just less than 350mm, the precipitation for the months of June to September accounted for 66% of it total and the mainly observed during the months of July-August, February to march records the lowest precipitation average of 120.9mm, with November to December have little or no rainfall. In the same precisely 7th July, the city of An Ling recorded in it history, very rare and short rainstorm with precipitation reaching 217mm, causing local flooding disasters.

## 3.9: Surface Water Resource

The abundant precipitation in the 50s does not come with economy development, this is because in the upper mountainous district, there is no large reserviour to check water, making easy mountainous runoff to Heng Shui Lake and reserviour through the river channel, and later flowing to the sea causing good water environment cycle. At the beginning of 1960, due the construction of many large, medium and small reserviour in the upper mountainous region, the surface water runoff was reduce and the most of the mountainous runoff were consume locally. Most river channel in Heng Shui were use only for piping floodwater in the rainy season thus becoming seasonal river, the continuous dryness experience since the 80s as well as the rapid human economic development, cause high amount of water usage and high water exploitation, making Heng Shui city one of the most lacked water region in China. The exhaustion of surface water makes most of the river channel dried, building sand and soil niche, desertification phenomenon increases. In 1993 and 1994, there was a complete dried up of Heng Shui Lake and thus presented a disastrous blow to the local aquatic water resource of this region. By 1958, there are 10 class and 40 species kinds of fishes in the Heng Shui lake, but at the turn of 1998, there are only 6 class and 20 species, the species extinction is as a result of water exploitation and occasional dry up, this extinction ofcourse presents a great harm to human, economic and ecological development. A great relieve came as a result of the introduction of Wei Channel project to Heng Shui, which supplement water resource, thus increase water capacity in Heng Shui lake.

This Surface water resource amount is directly related to the regional precipitation quantity and the ascending flow of water from other region. From 1993-2003 beyond, the city surface total water resource quantity ranges from 32.223 million to 3.4621 billion $m^3$. Various year annual average water resource is 731.8174 million $m^3$

### 3.9.1 Self Produce Surface Water Resource

**- Self Produce Surface Water Resource Amount**

According to the statistics of 1998, the ability of many industries, and agriculture to piped out water resource from the 18 water gates and pipe water gate in the New Fu yang, Fu yang, South China Qing Nan River and Fu Dong Pai river was great, the ability to pipe this water resource is $13000m^3/s$, the area have a total of 2700 water gate for irrigation. At present Heng Shui city have good water conservancy and the river flows interchange is visible everywhere, some human activities such as changing of dry field to wet field and afforestation have changed the subsoil character, thereby influencing the surface water distribution and water motion regulation. The self-surface water resource amount is deduced from the relation between precipitation and runoff.

### 3.9.2 Self Produce Water Runoff Distribution

Precipitation as well and drainage area subsoil integer factor varies, the differences in the annual runoff distribution exist at different land form and zones, although in Heng Shui plain, the precipitation difference is not too obvious, apart from subsoil layer burying capacity which is relatively large, other factor are relatively small. The reason being that, the self produced runoff at the top of the region does not varies that much. From the previous analysis, the many year precipitation for Jing cheng, Gu cheng, Wu qian is large, in the 50% annual certify rate, the self runoff average depth is as large as 10mm, while some year reaches 20mm. Amongst, Ji Zhuo water precipitation is very small, with it 50% certification rate runoff quantity of just 4.5mm.

### 3.9.3 Internal Annual Self Produce Runoff and Precipitation Variation

Variation of self produced runoff in one year or more in the city of Heng Shui, depict the character of Heng Shui runoff precipitation and this is obvious as its concentrated in one or two rainstorm rainy season, this makes the variation regulation of precipitation runoff in one year similar to that of its precipitation amount. The precipitation focuses on the months of July and August when the runoff is frequent and high, but for other months, there is no or little runoff. By the calculation of standard year analysis, in the year 50% certification rate, beside 4 counties and cities that present small runoffs in September, other cities and counties precipitation runoff occurs in July and August. See table 3-7 below for the runoff distribution at different certification rate, and for each administrative part in Heng Shui city.

Table 3-7 Different Administrative certified rate runoff statistical table in mm

| County | Control Area($km^2$) | Average Value R | Cv | Cs/Cv | Different Coefficient Rate Runoff | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 20% | 50% | 75% | 95% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Heng Shui | 8815 | 17.3 | 1.34 | 2 | 30 | 10 | 3 | 0 |
| Tao Cheng | 598 | 15.4 | 1.35 | 2 | 26 | 9.5 | 2.8 | 0 |
| Ji Zhuo | 918 | 11.8 | 1.7 | 2 | 20 | 4.5 | 0.6 | 0 |
| Zao cheng | 894 | 13 | 1.7 | 2.5 | 21 | 4.5 | 0.5 | 0 |
| Wu yi | 822 | 21.1 | 1.46 | 2 | 35 | 9.5 | 2.5 | 0 |
| Shen zhuo | 1244 | 16.7 | 1.47 | 2.5 | 27 | 7.5 | 1.8 | 0 |
| Wu qian | 451 | 23.3 | 1.4 | 2 | 39 | 11 | 2.7 | 0.5 |
| Rao yang | 573 | 17.6 | 1.45 | 2 | 32.5 | 9 | 2 | 0 |
| An ping | 493 | 18.7 | 1.61 | 2.5 | 30.5 | 7 | 1.8 | 0 |
| Gu cheng | 942 | 16.9 | 1.37 | 2 | 28 | 8.5 | 2 | 0 |
| JingCounty | 1183 | 21 | 1.36 | 2 | 38 | 12 | 3.5 | 0.5 |
| Fu cheng | 697 | 26.3 | 1.5 | 2 | 47 | 11.5 | 4 | 0 |

The influence of precipitation and runoff happening condition in this city varies, the yearly runoff variation is longer than the precipitation amount, by the analysis of runoff amount series of the year 1956-1998, the maximum depth of runoff is 109.9mm(1964) and the minimum is 0mm(1965, 1968). Fu cheng and Jing county runoff occurring coefficient is large, with it maximum annual runoff depth of 209mm (1964) and 150mm (1965) while the minimum is 0mm.the figure above illustrate the large variation in the runoff amount.

## 3.10: Import and Induce Water Amount

### 3.10.1: Import Water Amount

Heng Shui city induces surface water course from the following 8 set of rivers, Hu Tuo, Zhu Long, Fu Yang, New Fu Yang, Fu Dong Pai, Suo Lu, Qing Liang, Wei Yun. Owning to the climatic factors, large flood flow to the watercourse can cause increase in the water bodies. Before the year 1970, this watercourse had no water control blockage constructed, so this water only remain in the water way, but after the construction, there are large amount of water storage which is highly utilize for development, also in each year, there are the additional increase in reserviour built at various station e.g Wang Kuai reserviour at the upper river of Zhu Long River, Gang Nan and Huang Bi Zhuang reserviour at the upper course of Hu Tuo River, Lin Cheng, Zhu Zhuang, and Dong Wushi reserviour at the upper course of Fu Yang River and Yue Cheng reserviour at the upper course of Wei Yun River, hence causing annual river quantity to decrease. From the 1975 to 1984 total annual averages of 1.1714 billion $m^3$ flows into the river, while 1.0304 billion $m^3$ was discharge (Wei Yun which is at the boundary of Shan Dong province provides 50% of the importing water quantity). Shi Jin annual average water inducted accounts for 239 million $m^3$.

### 3.10.2 Induct Water Quantity

Presently there are a lot of important induced water irrigation project, we have Shi Jin induct irrigation water; induct Yellow River into Hebei, induced Wei Yun into Heng

Shui Lake. When the projects (the middle and the east line of the planned South to North water diversion) are implemented, there will be high quality water diverting into Heng Shui scope. Inducting water project will play an important role in improving Heng Shui water environment, which will indeed facilitate the economy development of Heng Shui City. Shi Jin certified water supply rate is extremely high. From 1961 to 1998, except for 1964 when the there was water flooding disaster, hence there was no induce water irrigation, other years had induced water irrigation records, the average annual water induced quantity was 239 million $m^3$ (Huang Bi Zhuang reseviour quantity), while the year 1979 produced the highest induced water quantity of 518 million $m^3$

Induced water always start from March, because that is when winter is disappearing, the return of wheat irrigation, springtime sowing, encountering drought, inducting water for irrigation is needed. In the year 1983, the drought in the spring, summer, and autumn were combined serially and the Shi Jin water channel induct water 3 times into irrigation areas, and this inducted irrigation water lasted for a period of 135 days.

The inducted Yellow River to Hebei province project was decided upon in the year 1992 march, at the $12^{th}$ conference by the Chinese agricultural integrated development leading team, this project was also incorporated into Huang Huai Hai plain, across provinces water conservancy projects. The project funded and implemented by three part, water conservancy ministry, and Shan Dong and Hebei provinces. In February 1993, 30 million $m^3$ was provided in the first phase and this water was imported through Wei Yun River into Hebei province.

In the year 1994, the inducted water quantity reaches 4 billion $m^3$ water provided by Wei shan inducting Yellow river to Hebei city, this project begins at inducting Yellow River Watergate at Weishan in Shan dong province, to Lin Qing city, then pass through the Wei Channel into the Xinkai Channel in Hebei Province, after which was inducted to Cang Zhou city through Qing Liang River. According to the proposals, Hengshui city would import water from the Yellow River to about 0.15 billion $m^3$. This water can replenish the ground water, relieve the strength of ground water exploitation at local places and improve surface and ground water quality. At the same time, parts of the water stored into Hengs Shui Lake would be used to relieve the water demanding pressure of agriculture, fishery, environment and electricity plant. The inducted water for the passed years was listed in Table 3-8 below.

Table 3-8: Amount of Annual Inducted Water in 100 million $m^3$

| Annual Distribution | Shi Jin Channe | Induce water from Wei Yun to Heng Shui | Induce water from yellow river to Hebei | Annual Distribution | Shi Jin Channel | Induce water from Wei Yun to Heng Shui | Induce water from yellow river to Hebei |
|---|---|---|---|---|---|---|---|

| | Induce water amount | Induce water amount | Induce water amount | | Induce water amount | Induce water amount | Induce water amount |
|---|---|---|---|---|---|---|---|
| 1970 | 3.06 | | | 1985 | 1.26 | 0.78 | |
| 71 | 2.52 | | | 86 | 2.60 | 0.07 | |
| 72 | 3.07 | | | 87 | 0.59 | 0.20 | |
| 73 | 0.51 | | | 88 | 0.44 | 0.40 | |
| 74 | 3.35 | | | 89 | 3.36 | 0.15 | |
| 75 | 2.77 | | | 90 | 1.31 | 0.15 | |
| 76 | 1.94 | | | 91 | 1.62 | 0.00 | |
| 77 | 2.70 | | | 92 | 4.18 | 0.00 | |
| 78 | 3.22 | | | 93 | 1.09 | 0.13 | |
| 79 | 5.10 | | | 94 | 1.58 | 0.08 | 1.25 |
| 80 | 2.65 | | | 95 | 1.74 | 0.06 | 0.75 |
| 81 | 1.50 | | | 96 | 2.45 | 0.00 | 0.00 |
| 82 | 1.82 | | | 97 | 2.98 | 0.00 | 0.84 |
| 83 | 3.72 | | | 98 | 4.12 | 0.13 | 1.19 |
| 84 | 2.64 | | | 99 | 1.59 | 0.00 | 0.79 |

We can also see that Heng Shui import more of it water from either Yellow River or the Shi Jin irrigation channel, from the year 1993-2003, the city imported accumulated water total was 3.013024 billion $m^3$, annual average of 273.9113 million $m^3$. Along the way, as the water from the yellow river passes, it distribute it water to various county while the surplus enters Heng Shui Lake, that which accumulated at the reserviour was 553.547 million $m^3$, of the annual average of 50.3225 million $m^3$; Shi Jin irrigation water accumulated import was 2.192511 billion $m^3$, and it annual average stands at 199.3192 million $m^3$

## 3.11: Ground Water Resource

The basics for ground water resource calculation, is the Shallow groundwater estimation utilization scale method process calculation, via many years total average replenishment quantity equals to total drainage quantity; deep layer groundwater estimation utilization limit quantity calculation method, hence taking deep freshwater layer replenished quantity as possible exploitation quantity.

From 1993-2003 period, Heng Shui city ground water resource mineralization water of 2g/l quantity is between 148.004-679.965 million $m^3$, averaging 360.7984 million $m^3$; 2-3g/l stands between 147.516-522.026 million $m^3$, averaging 331.155 million $m^3$, we can also notice that groundwater and tiny salt water resource are basically similar. If only we can utilize the part of the tiny salt water, then it can bring great relieved to water resource shortage in this city in the near future.

### 3.11.1: Shallow Layer Groundwater Resource Calculation Quantity

Shallow layer groundwater resource calculation relied on water average scale principle. Via some period of groundwater replenishment quantity equals total drainage quantity and groundwater storage variable summation.

$W_{Tot} = W_{ppt} + W_{Riv} + W_{Chan\ syst} + W_{Chan\ irrg} + W_{Well\ irrg} + W_{Resv} + W_{Side\ repl.}$

$W_{Tot}$; Total replenishment quantity ($10^4 m^3$)

$W_{Ppt}$; Induced replenishment Precipitation qty ($10^4 m^3$)

$W_{Riv}$; Watercourse seepage replenishment qty ($10^4 m^3$)

$W_{Chan\ syst}$; Channel system replenishment qty ($10^4 m^3$);

$W_{Chan\ irrg}$; Channel irrigation replenishment qty ($10^4 m^3$)

$W_{Well\ irrg.}$; Well irrigation Recharging amount ($10^4 m^3$)

$W_{Resv.}$; Store water system replenishment qty ($10^4 m^3$)

$W_{Side\ repl.}$; Side watercourse replenishment qty ($10^4 m^3$)

$W_{Tot\ Drainage.} = W_{Vap} + W_{Util.} + W_{Side\ drain} + W_{Excess\ drain}$

$W_{Tot\ Drainage}$; Total drainage qty ($10^4 m^3$)

$W_{Vap}$; Diving water vaporization qty ($10^4 m^3$)

$W_{Util.}$——Swallow groundwater utilization qty ($10^4 m^3$)

$W_{Side\ Drain.}$——Side watercourse drainage qty ($10^4 m^3$)

$W_{Excess\ Drain.}$——Excess flow drainage qty($10^4 m^3$)

Considering drainage area as well as the integrated water system, these two are convenient for water resource calculation and equation scaling, this city uses 3 drainage partition water resource sub-regions, according to the 11 administrative partition water resource sub-regions and 16 cell calculation (counties, cities, region as the basic) see the table below.3-9

Table 3-9: Heng Shui Water Resources Calculated Division Table

| DRAINGE DIVISION | | ADMINISTRATIVE DIVISION | |
|---|---|---|---|
| Ⅱ class Division. | Ⅲ class Division. | II class Division. | Ⅲ class Division. |

| Water res. Division | Area (km$^2$) | Single Cell | Area (km$^2$) | Regions | Area (km$^2$) | Single Cell | Area (km$^2$) |
|---|---|---|---|---|---|---|---|
| Qing Nan | | An Ping | 170 | Tao Cheng | 598 | Kun Fu Region | 448 |
| Region | 310 | Rao Yang | 140 | | | Hei Long Gang Dr | 150 |
| | | Ji Zhuo | 348 | Ji Zhuo | 918 | Kun Fu Region | 348 |
| | | Tao Cheng | 448 | | | Hei Long Gang Dr | 570 |
| Kun Fu | | Wu Yi | 283 | Zao Qian | 894 | Hei Long Gang Dr | 894 |
| Region | 3530 | Wu Qian | 451 | Wu Yi | 822 | Kun Fu Region | 283 |
| | | Shen Zhuo | 1244 | | | Hei Long Gang Dr | 539 |
| | | An Ping | 323 | Shen Zhuo | 1244 | Kun Fu Region | 1244 |
| | | Rao Yang | 433 | Wu Qian | 451 | Kun Fu Region | 451 |
| | | Ji Zhuo | 570 | Rao Yang | 573 | Qing Nan Region | 140 |
| | | Tao Cheng | 150 | | | Kun Fu Region | 433 |
| Hei Long | | Zao Qian | 539 | An Ping | 493 | Qing Nan Region | 170 |
| Gang | 4975 | Wu Yi | 894 | | | Kun Fu Region | 323 |
| Drainage | | Jing County | 1183 | Gu Cheng | 1183 | Hei Long Gang Dr | 1183 |
| | | Gu Cheng | 942 | Jing County | 942 | Hei Long Gang Dr | 942 |
| | | Fu Cheng | 697 | Fu Cheng | 697 | Hei Long Gang Dr | 697 |
| Whole City | 8815 | | | Whole City | 8815 | | |

Because of groundwater exploitation, utilization programming and cooperate harmonization (homogenous), this groundwater resource quantity still employ 57 items of groundwater resource in evaluating related results data.

### 3.11.2: Deep Layer Ground Water Resource Calculation Quantity

$\Delta Q = Q_{Repl} - Q_{Outlet}$

While $Q_{Repl} = Q_{Excess\ Flow} + Q_{Side\ Repl.}$ And

$Q_{Drainage} = Q_{Exploitation} + Q_{Side\ Drainage}$.

Where $Q_{Repl}$; Total deep layer ground water replenishment quantity

$Q_{drainage}$; Deep layer ground water total drainage quantity

$\Delta_Q$; Deep layer ground water storage charge quantity

$Q_{Excess\ Flow}$; Excess flow replenishment quantity

$Q_{Side\ Repl.}$; Side replenishment quantity

$Q_{exploitation}$; Deep layer ground water replenishment quantity

$Q_{Side\ Drainage}$; Deep layer ground water side drainage quantity.

### 3.11.3: Confined Water Related Quality Statistical Computation

**A) WATER TRANSPORT COEFFICIENT (T)**: From field experience, the Heng Shui city water resource utilization exploitation water transport coefficient was 1075 $m^2/d$.

**B) WATER LAYER AQUIFER ELASTIC DISCHARGE WATER COEFFICIENT**

**($\mu^*$)**: Field study of Heng Shui city electrical plant situated at Hou Pu reservation area, have an exploitation elastic discharging coefficient of 0.002, and it have in it system, an assumed coefficient average of 0.0032.

**C) DEEP LAYER AQUIFER ELASTIC DISCHARGING WATER QUANTITY**

$$\Delta Q = Q_{Elastic} = \mu^* \times \Delta H \times F$$

Where $\mu^*$ ----Deep layer aquifer elastic discharging water quantity

F-----Calculated regional area

$\Delta H$ --Change in the water layer calculated.

**COMPUTES WATER RESOURCES AND EXPLOITATION QUANTITY.**

**A) SURFACE WATER RESOURCE USEABLE QUANTITY**: On the basis of ground water resource computation, the exploitable assumed quantity was put at 50-60% (guaranteed the ecological water needs at the downstream district.)

**B) GROUND WATER USEABLE QUANTITY**: Shallow layer water exploitable quantity is computed as follow

$$Q_{Exploitation} = \rho \times Q_{Total\ Repl.}$$

Where $\rho$ is Exploitation Coefficient.

According to the principle of water balance, the exploitable water coefficient $\rho$ should be less than 1.0, that is, the total exploitable quantity should not be more than the total replenishable quantity. Also considering the geological condition in the balance district and the ground water replenishment condition, we can assume $\rho$ as 0.8.

**C) DEEP GROUND WATER LAYER USEABLE QUANTITY:** From field experience, the exploitation rate was much higher than the replenishment rate and hence result in the water table declining. For any optimization and sustainable water and city development, the exploitation quantity must equal or less the replenishment quantity, $Q_{Exploitation}=Q_{Repl}$.

**D) IMPORTED WATER RESOURCE USEABLE QUANTITY**: At present, the water imports are mainly from the Yellow River, Shi Jin irrigation channel. There is going to be a sharp increase to Heng Shui city and it lake, after the overall completion of the South to North water diversion project, and also subsequently importation from the Gang Nan, Huang Bin Zhuang, and Yue Cheng resources.

Field Studies have shown that, during several years water importation, the preliminary predicted water lost coefficient outcome for the Yellow River and YantZe River are 0.38 and 0.274 respectively and that of reservoir water lost coefficient is 0.3.

**E) RECYCLE WATER RESOURCE USEABLE QUANTITY:** According to the data provided by the water supply and demand planning in Hebei Province, the total useable recycle water resource quantity in Heng Shui City by the year 2010 will reach 110 million $m^3$. Though because of it present bad condition of the urban discharging channel water, the actual useable water quantity by the 2010 will be 20 million tons, and that of 2020 will reach 52.56 million tons.

**F) MINOR SALT WATER USEABLE QUANTITY**: The present cost of using utilization minor salt water is much higher than that of other water resources, so the minor salt water useable quantity is somehow restricted and limited, the normal practice is usually using the water resource for agricultural irrigation purpose, this possible by mixing the minor salt water with some surface water.

### 3.11.4: Shallow Ground Water Layer Control Exploitation Quantity

At the turn of 1980's, China economy development pick up fast, increase standard of living, the demand for water resource also increases exceedingly, shallow groundwater layer exploitation becomes serious, Heng Shui cities "Ji, Zao, Heng funnel" central water table continue to decline, hence we can make logical prediction towards the deep groundwater, establish limit exploitation blue print as well as mitigate soil sedimentation, water quality deteriorating progressive development.

Table 3-10: Heng Shui City Administrative Divisional Groundwater and Tiny Salt water Qty Unit:$10^4m^3$

| ADMI-NISTRA-TIVE REGION | SUMMATION | | | <2g/L | | | 2-3g/L | | |
|---|---|---|---|---|---|---|---|---|---|
| | Resource Qty | Replenis-hed Qty | Available Exploitable Qty | Resource Qty | Replenis-hed Qty | Available Exploitable Qty | Resource Qty | Replenis-hed Qty | Available Exploitable Qty |
| TaoCheng | 5074.7 | 5483.8 | 3742.5 | 1374.0 | 1518.7 | 1085.9 | 3700.7 | 3965.1 | 2656.6 |
| Ji Zhuo | 10899.2 | 11386.3 | 2066.5 | 2066.5 | 2203.1 | 1586.2 | 8832.7 | 9183.2 | 6136.3 |
| ZaoCheng | 11528.0 | 12604.4 | 7237.2 | 7237.2 | 7996.3 | 5757.3 | 4290.8 | 4608.1 | 3087.4 |
| Wu Yi | 7858.6 | 8467.5 | 5894.8 | 4046.3 | 4429.8 | 3189.5 | 3812.3 | 4037.7 | 2705.3 |
| ShenZhuo | 11684.9 | 12409.7 | 8421.1 | 2487.6 | 2664.1 | 1891.5 | 9197.3 | 9745.6 | 6529.6 |
| Wu Qian | 6380.8 | 7049.3 | 4869.2 | 3236.6 | 3653.9 | 2594.3 | 3144.2 | 3395.4 | 2274.9 |
| Rao Yang | 7995.2 | 8971.8 | 6279.8 | 4915.7 | 5373.1 | 3868.6 | 3079.5 | 3598.7 | 2411.2 |
| An Ping | 7852.9 | 9366.0 | 7140.2 | 7405.2 | 8837.9 | 6786.4 | 447.7 | 528.1 | 353.8 |
| Gu Cheng | 16040.5 | 16902.1 | 11972.6 | 12211.2 | 12963.3 | 9333.6 | 3829.3 | 3938.8 | 2639.0 |
| Jing County | 18166.3 | 19330.7 | 13630.8 | 12657.8 | 13585.9 | 9781.8 | 5508.5 | 5744.8 | 3849.0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fu Cheng | 8523.5 | 9204.5 | 6394.2 | 4168.7 | 4543.9 | 3271.6 | 4354.8 | 1660.6 | 3122.6 |
| Whole City | 112004.6 | 121176.1 | 84912.4 | 61806.8 | 67770.0 | 49146.7 | 50197.8 | 53406.1 | 35765.7 |

According to the Heng Shui city Exploitation status as well as water civil soil quality condition, first we select exploitation replenishment equilibrium method, in calculating possible exploitation quantity, taking deep freshwater layer replenishment quantity as the possible exploitation quantity.

$Q_{Availability}=Q_{Replenishment}$

Aim at Heng Shui City regional circumstances $Q_{Replenishment}=Q_{Side\ input}-Q_{Side\ output}+Q_{Excess\ flow}$

Therefore：$Q_{Side\ Input(Output)}=\triangle t\times J\times T\times L$

Amongst： Δt——Calculation time（d）

T——Transmit water coefficient (m2/d)

L——Side watercourse in (out) boundary stop surface length (m)

J——Waterpower gradient (m)

$$Q_{Excess}=K_z\Delta t\frac{\overline{h_2}-\overline{h_1}}{\bar{l}}\cdot F$$

Amongst：K——Hand down direction Infiltration coefficient(m/d)

Δt——Calculation time（d）

$h_1$——Shallow water calculated region at Δt period of average water level elevation (m)

$h_2$——Deep water calculated region at Δt period of average water level elevation (m)

I——Hand down direction excess flow length (m)

F ——Excess flow area ($m^2$)

The calculated regional scope of the city deep freshwater layer area was 8815$km^2$, and a calculated depth of 160–350m. Transmit water coefficient T employ ground water prospect, field pump water experimentation; Kz selected from (Huang Huai Hai plain) ((Hebei part) water surface quality synthesize estimation groundwater resource special report)) having related data, combine each integer city, county, lithology, trans stream, plus the weight average, and the outcome of the calculation is vertical infiltration coefficient. See deep freshwater layer exploitation calculation table 3-11 results below

Table 3-11: Heng Shui City Deep Layer Freshwater Exploitation Qty Schedule in $10^4 m^3$

| Regions | Input/Output Diff | $Q_{Excess}$ | Exploitation Limit | Remark |
|---|---|---|---|---|
| Tao Cheng | 1350 | 1550 | 2900 | |
| Ji Zhuo | 669 | 1987 | 2656 | |
| Zao Cheng | 282 | 1822 | 2104 | |
| Wu Yi | 843 | 2108 | 2951 | |
| Shen Zhuo | -1350 | 5144 | 3794 | |
| Wu Qian | -165 | 1512 | 1347 | |
| Rao Yang | 147 | 1888 | 2035 | |
| An Ping | 48 | 1499 | 1547 | |
| Gu Cheng | -341 | 1622 | 1281 | |
| Ji Cheng | 174 | 1864 | 2038 | |
| Fu Cheng | -168 | 1828 | 1659 | |
| Total | 1488 | 22824 | 24312 | |

### 3.11.5: Total Water Quantity

One area total water resource quantity depend on the area precipitation production of surface ground and groundwater resource summation, present surface water and ground water resource quantity difference are calculated with respect to the circumstance, and we are requires to subtract both of their repeated water quantity.

The city surface water resource quantity serve as the city self produce water quantity, ground water resource as ground water total replenishment quantity subtracted well irrigated recharged quantity. The two repeated quantities include surface water body system induced seepage replenishment quantity and river plain basic runoff quantity. Because large part of the city region groundwater table is under the river water table, hence it basic runoff quantity is ignored in calculation. After the analytical computation, the city surface water resource quantity were 195.14 million $m^3$; ground water resource quantity 618.07 million $m^3$, deep and shallow freshwater resources total quantity 735.1 million $m^3$, and 227.26 million $m^3$. The above water resources quantities do not include 2-3 and 3-5g/L of tiny salt-water quantities. See table 3-12 below for each administrative sub region, drainage area sub region different annual water level, different water quality resources calculated quantity table.

Table 3-12 Heng Shui Divisional Total Freshwater Qty Aggregate Table Unit Unit：$10^4 m^3$

| Regions | Area ($Km^2$) | Surface Water Res. Qty | Ground Water Res. Qty | Repeated Calculated Qty | Total Fresh Water Qty | Human Average Consumption |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| Tao Cheng | 598 | 1064.4 | 1370.0 | 520.0 | 1918.4 | 54.8 |
| Ji Zhuo | 918 | 1459.6 | 2066.5 | 120.0 | 3406.1 | 93.4 |
| Zao Qian | 894 | 1430.4 | 7237.3 | 80.0 | 8587.7 | 232.2 |
| Wu yi | 822 | 1997.5 | 4046.3 | 220.0 | 5823.8 | 191.3 |
| Shen Zhuo | 1244 | 2463.1 | 2487.6 | 1230.0 | 3720.7 | 66.7 |
| Wu Qian | 451 | 1023.8 | 3236.6 | 120.0 | 4140.4 | 203.7 |
| Rao Yang | 573 | 1260.6 | 4915.7 | 670.0 | 5506.3 | 200.0 |
| An Ping | 493 | 1114.2 | 7405.2 | 1270.0 | 7249.4 | 240.4 |
| Gu Cheng | 942 | 2006.5 | 12211.0 | 1680.0 | 12538.0 | 288.1 |
| Jing County | 1183 | 3288.7 | 12658.0 | 1870.0 | 14077.0 | 293.8 |
| Fu Cheng | 697 | 2404.7 | 4168.7 | 30.0 | 6543.4 | 206.1 |
| Whole City | 8815 | 19514 | 61807.0 | 7810.0 | 73510 | 185.8 |

## 3.12 Water Resource Exploitation Utilization

### 3.12.1: Surface Water Resource Status

**-Self Produce Water Quantity**

In 1998, the city total self produced surface water was 152 million $m^3$, 16 million $m^3$ less compare with many years average annual value of 168 million $m^3$, accounting for 10% annual shortage average only, and it annual average flow depth of 1.8mm. From administrative aspect: Jing county runoff production is very large, it annual average flow depth is 10.6mm, next is Fu cheng County 2.8mm, Gu cheng county 0.9mm, Zao qian 0.3mm, while other city average was approximately zero.

In 1998, the total water import to the whole city river was 170 million $m^3$, export stands at 146 million $m^3$, the difference between the import-export water quantity is 24 million $m^3$; Huang Ma channel import 2.355 million $m^3$ of water quantity to Heng Shui Lake; Wei yun 13 million $m^3$, Shi Jin channel 412 million $m^3$, that is the year with the greatest water quantity import. Towards the end of 1998 to the early part of 1999, Heng Shui City utilize water imported from Yellow river to the amount of 98.9

million $m^3$, among which 56.6 million $m^3$ were stored in Heng Shui lake. In the year 1998, the whole city utilizes a total of 535-million $m^3$ water quantity from other city.

This surface water are mostly use for agricultural irrigation and power plant cooling system, for the 1993-2003 period, the excess annual year water quantity exploited was 328.827818 million $m^3$, accounting for 20.51% of the city total, 1998 recorded the highest exploitation so far amounting to 611.29 million $m^3$, while the least was recorded in the year 1993 with 141.061 million $m^3$.

***MAJOR WATER RESOURCE USERS IN HENG SHUI CITY***

The three major water resource users in this city are agriculture which takes the leading role in water consumption, it accounted for almost 90% of the city water usage, in the year 2003, it utilizes 1.335595 billion $m^3$ of water resource of the total 1.539859 billion $m^3$ i.e 86.7%. Along with the current industrial structure as well as improvement in irrigation technique, agriculture water resources usage will definitely reduce and this will bring a lot of relieved to water shortage. Secondly, is the Industrial sector, from the year 1993-2003, this sector utilizes 63.060091 million $m^3$, accounting for 4.11%, but with growing economic development, there is the great possibility of industrial growth and subsequently water usage, for example, in the year 1993, it utilizes 50.605 million $m^3$ but in the year 2003 it increases to 85.235 million $m^3$ making annual increase of 3.139182 million $m^3$ (5.65%). Lastly is the domestic drinking water consumption, this include, Livestock and domestic water uses, which is practically the basis for existence, as for the year 2003, the city domestics and subsistence livestock water uses accumulated usage was 119.128 million $m^3$, serving a population of 4.108 million people, hence we can conclude that the average human consumption then was less than 80L, compare to China average of 150L i.e 50%. Also we can notice that the water works supply quality has a PH 8.32-8.75, exceeded the standard coefficient by 74.20%, Fluorine water stands at 0.89-1.76mg/l, and also exceeded the standard coefficient by 85.71%. This ofcourse affect the already insufficient water quantity requirement, which calls for prompt action.

**-Present Water Resource Exploitation and Utilization Status**

Going through Heng Shui water resource for 1993-2003 period-related statistics, see table 3-13 below. Except for imported water, the city focuses on surface water for it water resource, which practically continue to decline annual. It average shortage sometimes reaches 1.1184153 billion $m^3$ without water import, shortage coefficient of 53.30-90.89, it average shortage coefficient stands at 72.42%. Eventhough supplementing shortage by imported water, several years yet lacked water resource except for 1996, 2000, and 2003 periods, which have surplus, this surplus inevitably cannot meet the future water demand. The average annual water shortage quantity with water import was 154.7392 million $m^3$, accounting for annual water shortage coefficient of -3.61%. This shortage yet put great pressure on water usage, thus resulting in the great exploitation of groundwater. The pressure could be more if precautionary measures are not taken. See table 3-13 below and compare that to Table 4-2, the predictive value for the water-planning period 2006-2030.

Table 3-13 Comparing 1993-2003 Heng Shui city total water resource and utilization quantity Unit：10,000$m^3$

| Year | City water supply quantity | After Importation, Available utilize water resource qty. | Practical total water usage | Non Induct Water | | After Induct Water | |
|---|---|---|---|---|---|---|---|
| | | | | Shortage Qty | Shortage Coefficient (%) | Shortage Qty | Shortage Coefficient (%) |
| 1993 | 58352.6 | 60565 | 126909.9 | -68557.3 | -54.02 | -66344.90 | -52.28 |
| 1994 | 32826.7 | 75922.4 | 142220 | -109393.3 | -76.92 | -66297.60 | -46.62 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1995 | 45503.6 | 109053.8 | 140490.6 | -94987 | -67.61 | -31436.80 | -22.38 |
| 1996 | 50672.6 | 438662.1 | 117482.1 | -66809.5 | -56.87 | 321180.00 | 273.39 |
| 1997 | 14800.4 | 71967.1 | 162432 | -147631.6 | -90.89 | -90464.90 | -55.69 |
| 1998 | 29752.5 | 87978.1 | 183774.3 | -154021.8 | -83.81 | -95796.20 | -52.13 |
| 1999 | 15815.1 | 42767.7 | 166181 | -150365.9 | -90.48 | -123413.30 | -74.26 |
| 2000 | 56649.7 | 203286.8 | 162073 | -105423.3 | -65.05 | 41213.80 | 25.43 |
| 2001 | 40087.8 | 110175.7 | 154184 | -114096.2 | -74.00 | -44008.30 | -28.54 |
| 2002 | 26782.7 | 84615.7 | 163700 | -136917.3 | -83.64 | -79084.30 | -48.31 |
| 2003 | 71892.3 | 218185.3 | 153945.9 | -82053.6 | -53.30 | 64239.40 | 41.73 |
| Annual Average | 40285.09 | 136652.7 | 152126.6 | -111841.53 | -72.42 | -15473.92 | -3.61 |

Note：Shortage coefficient =( Total water shortage Qty/Total water utilization )×100%，“-” Denote lacked； “+” Denote Abundance.

### 3.12.2: Groundwater Resource Status

**-GroundWater Resource and Available Utilization Quantity**

In 1998, the city just produced total groundwater resource quantity of 282 million $m^3$, in addition to the 2-3g/L and 3-5g/L of tiny salt-water quantity; the whole city total ground water quantity was put at 619 million $m^3$. Shallow layer groundwater possible recharge utilization quantity was 253 million $m^3$, and deep layer groundwater limited utilization was 243 million $m^3$, secondly, adding practical groundwater permissibility utilization quantity of 496 million $m^3$.

Most of these ground water exploited are from three main origin, the deep freshwater layer, shallow freshwater layer, and the shallow tiny salt water layer and it prioritized exploitation is in that order. From the year 1993-2003, deep freshwater layer annual average exploitation amount was 741.6937 million $m^3$, with 907.81 million $m^3$ being the highest amount among this period in question 1998; while 487.184 million $m^3$ is the quantity exploited from shallow freshwater and that of annual average for tiny salt water was 20.53891 million $m^3$, the highest of one of it year being 30.121 million $m^3$.see table 3-15

### 3.12.3 GroundWater Potential Dynamic Analysis

**-Shallow Layer GroundWater Dynamic**

By the end of 1998, the city shallow layer groundwater average burying depth was 8.90m, deeper than the previous year by 0.66m, apart from Gu Cheng groundwater potential cycle rising to 2.04m, other counties were declining, among which Zao Cheng has the greatest decline scope of 1.96m.

During the low water table period of July 1998, An Ping, Rao Yang, and the north part of Shen Zhou strip groundwater burying depth averaged 15m. Among which An Ping south of Wang Zhuang has the deepest, 27.78m. Large part of Wu Qian, west part of Shen Zhuo, and Southwest part of Ji Zhuo is region with low burying depth of only 5m, also Wu Qian Liu Guai and Shen Zhuo Da dun strip burying depth were only 3m, and other region was 5.0-15.0m. Owning to period of flooding, precipitation quantity was always relatively small, comparing the high and low water period, 6 counties out of the 11 found in the north and east part has their water potential cycling rising, while the rest are declining.

### INDUSTRAILIZED UNIT SELF PRODUCE EXPLOITATION WATER RESOURCE

Presently each enterprise commonly possesses 141 unit of their own water well, supplying annual water quantity of 14.687 million m3/d resource well, among which the greatest user of these water resources are, Family Hospital, Cotton Spinning factory, Heng Shui Power Plant, Teachers technological academic, and the city pharmaceutical factory.

### AGRICULTURAL IRRIGATION WATER EXPLOITATION

According to year 2002, Hebei water conservancy statistical resource, the city accumulated a total of 70358 unit of well, covering a total area of 3634.6km$^2$, it irrigated water amount to 1.04 billion m$^3$, among these, Tao Cheng has 2039 units of well, producing 56 million m$^3$ of water resource and covering an area of 151.6km$^2$, while Ji Zhuo had 3457 unit supplying 85 million m$^3$ of water and covering an area of 313.6 km$^2$.

### INDUCE IRRIGATION WATER.

Heng Shui city external induct water include that from Yellow river, Wei Yun as well as that from Shu Jin irrigation channel, apart from the amount of water that are store in Heng Shui lake, large portion are use along the way for agricultural purposes, for the year 1993-2003, the total water resource accumulated and used for agricultural purpose reaches 2.54728 billion m$^3$.

For the 1994, the yellow River annually, single handedly deposited 150 million m$^3$ of water into Heng Shui Lake, which is store and later distributed for use. According to available data, apart from the deducting the water that is use along the way for agriculture during importation, the Yellow River practically import 116.45 million m$^3$ of water, among it 44 million m$^3$ is lost during transport, while only 72.2 million m$^3$ enter the city. The city annual water rate of vaporization stands at 20.41 million m$^3$, while annual seepage account for 20.59 million m$^3$. To the year 2002, the many years water importation to Heng Shui accumulated to 259.95 million m$^3$, and ofcourse this water are use for agricultural irrigation, power plant cooling system and Ecological purposes.

### THE ORIGIN OF THESE WATER RESOURCE

The basic origins of these water resources are principally four, ground water, surface water, imported water, and recycling water. The table below shows the origin and the amount it produces, and it usage capacities while the pie chart also shows the exploitation, supply and usage of each use.

Table 3-14: 1993-2003 water resource origin-supply-usage unit: 10,000$m^3$

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Exploitation Quantity | Types | Ground Fresh Water | Tiny Salt Water | Surface Water | Imported Water | Polluted water | | Total |
| | Average Value | 29635.17273 | 26773.98182 | 80640.89091 | 27391.12727 | 3130.557 | | 167571.7297 |
| | Total % | 17.69 | 15.98 | 48.12 | 16.35 | 1.87 | | 100.00 |
| Supply Quantity | Types | Deep Fresh Water Layer | Shallow Fresh $H_2O$ Layer | Tiny Salt Water | Surface Water | Imported Water | Sewage Recycling Uses | Total |
| | Average value | 74169.3727 | 48718.4000 | 2053.8909 | 32882.7818 | 2476.0182 | 18.1818 | 160318.6455 |
| | Total % | 46.26 | 30.39 | 1.28 | 20.51 | 1.54 | 0.01 | 100.00 |
| Utilization Quantity | Types | Industrial $H_2O$ Uses | Agric. Irrigation Use | City Domestic $H_2O$ Uses | Subsistence Livestock $H_2O$ Uses | | | Total |
| | Average Value | 6306.0091 | 137250.2273 | 2389.2818 | 7556.6818 | | | 153502.2000 |
| | Total % | 4.11 | 89.41 | 1.56 | 4.92 | | | 100.00 |

According to the table above, in comparing the exploitation of water resource, we can see that the exploitation of surface water is almost 50%. Ground freshwater, saltwater and imported water were all approximately 16%. However the practical exploitation supply of ground freshwater is so obvious, accounting for 76% (deep and shallow fresh water layer), while that of surface water is just 20.51%, tiny salt water 1.28%. The exploitation of groundwater have already exceeded it limit, and should be done with more caution and control. Surface water resource account for 57.38% of potential non excavation, but salt water resource utilization is relatively small, accounting for 14%, so also in the imported water utilization. In general there are great imbalance in the supply of water resource and this is one area that must be manage as well as expanding surface water, tiny salt water, imported water exploitation for sustainable development

Fig. 3.3: 1993-2003 annual water resources exploitation quantity pie chart

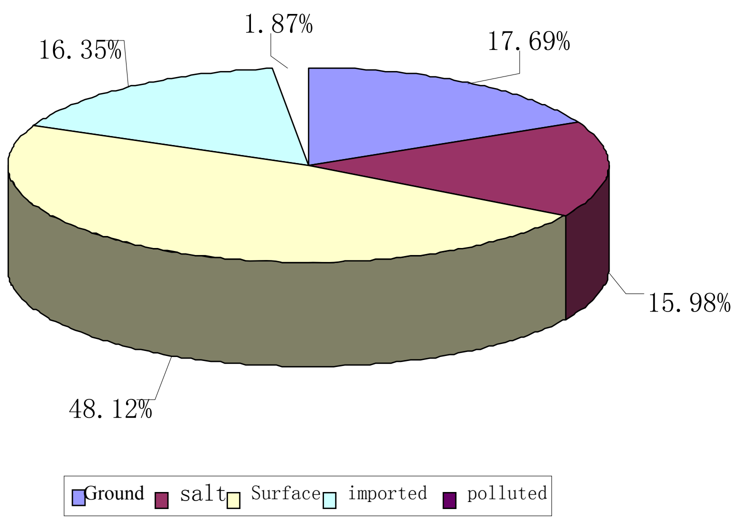



Fig.3.4: 1993-2003 Annual Water Supply qty Pie Chart

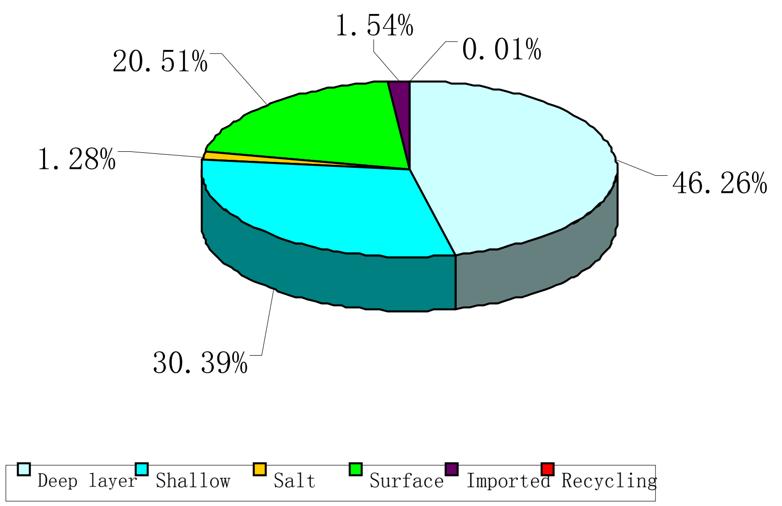
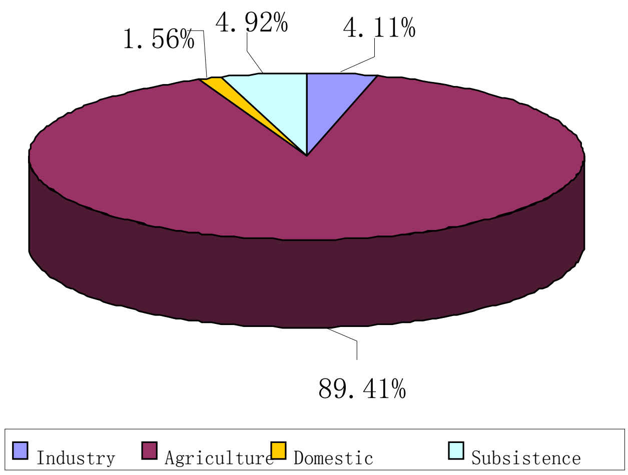


Fig 3.5: 1993-2003 Annual Average Utilization Chart




Form the water usage above, irrigation account for 89.41%, industry 4.11%, subsistence livestock 4.92%, city drinking water just 1.56%, from the ongoing we can conclude that irrigation is the most important water consumption activities, although from the city 2002 GDP, agriculture only contributed 34.77% GDP of that of Industry, hence there is the school of thought who are proposing reduction in water resource with regards to agriculture, but the pressure is yet to abate. These and many questions are yet to be answered.

Table 3-15: 1993—2003 comparison between Supply and water Usage quantity in 10,000 $m^3$

| YEAR | SUPPLY WATER QUANTITY | | | | | | | | USAGE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GROUND WATER | | | | SURFACE | IMPORTED | RECYCLE | SUMMATION | INDUSTRY | IRRIGATION | DOMESTICS | SUBSISTANCE | SUMMATION |
| | DEEP | SHALLOW | SALT | TOTAL | | | | | | | | | |
| 1993 | 49833.3 | 58261.3 | 2310 | 110404.6 | 14106.1 | 2399 | 0 | 126909.7 | 5060.5 | 112996.8 | 1214.2 | 7638.4 | 126909.9 |
| 1994 | 70262.5 | 41847.8 | 1369.4 | 113479.7 | 28739.5 | 0 | 0 | 142219.2 | 5523 | 127710.2 | 1437.8 | 7548.2 | 142219.2 |
| 1995 | 62624 | 35282 | 756 | 98662 | 52152 | 7378 | 17 | 158192 | 4868.5 | 132122.9 | 2564.3 | 8872.2 | 148427.9 |
| 1996 | 40103 | 54434.6 | 1279.4 | 95817 | 50837 | 806 | 1.5 | 147460 | 5719.5 | 102783 | 1132.9 | 7848.2 | 117483.6 |
| 1997 | 77713 | 49309 | 2922 | 129944 | 39760 | 2660 | 1.5 | 172364 | 5992 | 147603 | 1917.5 | 6921 | 162433.5 |
| 1998 | 90781 | 54784 | 2463 | 148028 | 61129 | 0 | 0 | 209157 | 6156 | 168510 | 1673.3 | 7435 | 183774.3 |
| 1999 | 88294 | 47762 | 2181.4 | 138237 | 29439 | 3800 | 47 | 171476.4 | 6188 | 155803 | 2359 | 7173 | 171523 |
| 2000 | 84723 | 42015 | 1589 | 128327 | 31913 | 3537 | 13 | 163777 | 6743.3 | 147089.7 | 3033 | 6937 | 163803 |
| 2001 | 79108.5 | 46021.2 | 1699 | 126828.7 | 25050.1 | 2265 | 40 | 154143.8 | 7269.9 | 136447.3 | 3352 | 7154.6 | 154223.8 |
| 2002 | 90357.5 | 54294 | 3012.1 | 147663.6 | 14558 | 1438.5 | 40 | 163660.1 | 7331.8 | 145127.1 | 3701.4 | 7579.8 | 163740.1 |
| 2003 | 82063.3 | 51891.5 | 3011.5 | 136966.3 | 14026.9 | 2952.7 | 40 | 153945.9 | 8513.6 | 133559.5 | 3896.7 | 8016.1 | 153985.9 |

**-Deep Layer GroundWater Dynamics**

The excessive exploitation of deep layer groundwater resulted in the successive annual water resource declination. In 1998, the whole city deep layer ground water exploitation reaches 908 million $m^3$, greater than the previous year by 131 million $m^3$, towards the end of the year, the whole city average deep layer water burying depth is 49.46m, greater than previous year by 3.30m, by the end of July 1998 the famous Ji, Zao, Heng great funnel center burying depth reaches 81.04m, which is also greater than previous year by 5.36m. This city funnel region area is 8201 $km^2$, accounting for 93%.

### 3.12.4: Utilization Water Status

By the turn of 1998, the total water used was 1.84 billion $m^3$, agriculture utilize most of 1.784 billion $m^3$, accounting for 89.13%, industrial and household used 6.16 million $m^3$ and 1.67 million $m^3$, accounting for 3.34% and 1.0% respectively. From administrative aspect, Shen Zhuo uses the largest water quantity of 360-million $m^3$ and Wu Yi 221 million $m^3$. While Ji Zhuo and Wu Qian uses the smallest water quantity of 94 and 103 million $m^3$. See table 3-15 above for the water utilization.

### 3.12.5: Water Supply Status

The whole city present total main watercourse and relatively big tributary project are 95, induct water project are 70, draw water project are 56. As of 1998, the reserviour project store a total water capacity of 70 million $m^3$ of inducted water quantity (including Yellow river and Shi Jin channel), which supplies 539 million $m^3$, Heng Shui lake store 61 million $m^3$. At present the city supply have 62503 unit of well, among it 21499 and 41004 are deep and shallow well respectively, there are 6 project in the whole city which get more than 1 million $m^3$ water quantity annually. In 1998, groundwater supply quantity reaches 1.466 billion $m^3$. Among which deep freshwater and shallow freshwater quantity are 908 million $m^3$ and 547 million $m^3$ respectively, excluding tiny salt water.

### 3.12.6: Excess Exploitation Quantity Analysis

In 1998, the total groundwater resource quantity was only 282 million $m^3$, the available exploitation quantity was 253 million $m^3$, deep layer groundwater limited exploitation quantity was 243 million $m^3$, in addition, practical groundwater permissibility exploitation was 496 million $m^3$, and moreover all in all, 1.466 billion $m^3$ of practically water quantity was derivable in the year 1998. Excess exploitation reaches 970 million $m^3$, accounting for 29.56% of the practical water permissible exploitation quantity. Among this amount is the deep layer ground water exploitation, which reaches a total of 908 million $m^3$, excess exploitation of 665 million $m^3$. The city average groundwater burying deep of that year exceeded the previous year by 3.30m, and reaches 49.6m, deep layer groundwater exploitation exceeded it limit seriously, persistent declining, making groundwater exhaustion a serious issue.

From the ongoing it is inevitably to import water from elsewhere in order to the supplement the already insufficient water shortage (See Table 3-13) and to reduce if not stop the excessive groundwater exploitation. The only alternative to reduce temporarily the shortage is the South-North Water Diversion, which are already in place, which in no doubt will supplement water supply in Heng Shui City.

## 3.13 South to North Water Diversion Project

Zhang Jiacheng, Vice-President of the China Institute of Meteorology, said in the article titled "Acting in Accordance With Natural Law" on August 28, 2000 for the Beijing Review, "China is prone to drought and flooding, and devastating disaster of these kinds which tend to attack north and south China simultaneously. Hence, there is no need for water diversion, the long-distance large-scale water diversion from the south to the north is not practical or economically viable.( Zhang, Zhiping, 2000). We could disagree with Mr. Zhang's statement in two ways. He is correct that China is prone to drought and flooding, but most droughts happen in northern China, north of Changjiang River, and most of the large scale flooding occurs in the south and along the Changjiang River. Year 2002, China's longest river, the Changjiang River, spilled over its banks, killing hundreds and destroying both homes and lives. More than 1,500 died during the flooding. The People's Daily, the Communist Party's flagship newspaper, reported that the 2002 flood season also "victimized" 190 million people.

Slightly more than one million homes were destroyed, and almost 33 million acres of cropland were affected. Four years ago, the great flood swept along the Changjiang River and more than 4,000 people were killed. Clearly, there is a surplus of water in south China whereas there is a clear water shortage in North China.( Chang, Gordon G.2002) .As floods ravaged the middle of the country last year, a draught parched the north. Tianjin and Shandong Province faced their worst water shortage in a century, and rainfall in that year and the year after have been about half of what they should be. Shandong's plight is ironic: the province has a long coastline but yet it remains in dire need of water.

Thus, Construction of the South-to-North Water Transfer Project is not an option; it is a necessity for the sustainable development in northern China of which Heng Shui city is inclusive. According to geography of China, two-thirds of its agriculture is in the north, but four-fifths of its water is in the south. Of the five watersheds where most of the country's people and farms are concentrated, Huanghe, Huaihe, Haihe and Liaohe River Basins, more than 550 million people are concentrated in the arid north.( Lester R. Brown and Brian Halweil 2003) .Thus, the water shortage in north China not only affects more than half of the Chinese population's quality of life, but also limits its future industrialization and urbanization processes. China will experience its most serious water shortage after 2010. The water shortages resulted in an annual loss of industrial output amounting to 100 billion Yuan (U$12 billion), (F.Peng.peopledaily 2003) .How can China solve the problem of the increasing deficit of city water in the process of urbanization? Active countermeasures must be taken to miltigate against water deficit in these cities. Hence, the Chinese government's decision to construction the South-to-North Water Transfer Project will not only to improve the quality of life in the north, but also ensure continued sustainable development in the 21century. It will also minimize an annual loss of industrial output significantly, because water diverted from the eastern route will mainly be used for industrial and urbanization subsequently sustainable development is ensured.

An analysis offered by the Ministry of Water Resource shows that once the initial phases of the eastern and central routes are completed, they would bring an increased annual direct economic return of 55.3 billion Yuan (U$6.7 billion). China possesses 2,800 billion $m^3$ of water resources, ranking the sixth in the world. But in respect to water volume commanded per capita it is only 2,300 $m^3$, amount to one fourth the average amount per capita around the world and China has been listed by U. N. as one of the 13 countries with a water deficit. Thus, China has a water shortage.( Wei, Xue 1996)· Since the founding of the People's Republic of China, the Chinese government has exercised the leadership of the people throughout the whole country to construct water conservancy works on a large scale and has gained great achievements. However, water-related problems are still hindering the Chinese economic and social development of which Heng Shui is a part. The sustainable utilization of water resource is the key problem for the economic and social development in China.( Zhang Chun Yuan.pdf 2003)

According to the Chinese government statistics, China will need 698.8 billion $m^3$ of water in 2010, while the water supply is only 667 billion $m^3$, leaving a gap of 31.8 billion $m^3$. The situation will worsen in 2030, with the gap widening to 50 billion $m^3$.( Peopledaily 2003)

For many years, the dry-outs have repeatedly occurred in the Huanghe River has seriously affected the economic development in the region. China is also a country with frequent floods. While many northern cities in China including Heng Shui the city in question suffer from water deficit, some places often suffer from floods caused by water surplus. Both temporal and geographic rainfall distributions in China are uneven.

The problems of water resources and water environment are complex and mainly reflected in three aspects: the flood disasters, a major concern for a long time, the shortage of water resources, an increasingly evident limiting factor to development, and the water pollution which has a direct negative effect on economic development and quality of life in China.

Population expansions, and rapid economic development, particularly industrialization and urbanization, are increasingly demanding more water resources, imposing requirements for both quantity and quality of water. To completely solve these problems requires the support by a strong economy. However, China is still a developing country and its economy and technology are still under-developed, which largely affects the exploration and utilization of water resources, and vice versa.

Water resources and economic development are two contrasting factors, affected and restrained by each other**.** The Chinese government has always attached importance to the exploration, utilization and conservation of water resources. Better planning, exploration, utilization, and the conservation of water resources is critical for efficient and sustainable water use. The solution to these problems relies largely on modern science and technologies.

## 3.14 Conclusion remarks

The implementation of the South-to-North Water Transfer will basically realize a relational water resources allocation in the areas of the 4 major river basins, i.e., Changjiang, Huaihe, Huanghe and Haihe. It will greatly improve ecological environment and promote economy development in North and Northwest China. The huge project, consisting of 3 routes, i.e., ERP, MRP and WRP, will involve extreme complicated factors and most challenging tasks, such as, complicated geological conditions, difficult engineering techniques, delicate eco-environmental problems as well as tall intricate management and operation. It is necessary for engineers, scientists, managers and decision-makers to have scientific concepts in works, to follow natural laws in practice, to continuously modify ideas and plans according to the project execution and to play full function of the project in a comprehensive way. This way we could plan sustainably, using the water resources available predicting accurately, thus infact necessitate a good predicting technique for decision makers, hence the next two chapter deals with the applicability of Forcasting statistical method and the employment of Water Evaluation and Planning System (WEAP) to planned consciously and accurately given the available variable, supplementing the traditional water import. This model will infact make prediction accurately for proper decision-making and thus enhancing sustainability and City development not only for Heng Shui but China as a whole.

# CHAPTER FOUR

## ANALYSIS OF FINDING, FORECASTING AND SIMULATION MODEL

## 4.1 Introduction

The purpose of this chapter is to describe the methodology used in the Regional Water Facilities Planning analyses in Heng Shui Municipality. The study challenge was to look at changing supply and demand patterns over the next 30 years and make reasonable predictions about what additional facilities, if any, would be needed to reliably meet these changing demands.

First, this chapter reviews the underlying concepts of the facilities master planning process and the probabilistic approach applied to facilities planning. The balance of the chapter describes the methodologies used to determine supply and demand probability distributions in the future and the subsequent modeling of existing baseline and future facilities infrastructure against these probability distributions. The goal was to determine the reliability of Municipal water systems through the year 2030 and make recommendations for facilities to meet the Municipal's mission of a safe and reliable water supply.

**Water Facilities Master Planning Process**

The water facilities master planning process is composed of three interrelated components: water demands, water supplies, and facilities. Facility planning began with estimating future water demands, proceeded to the identification of water supplies and their reliability, and then to the identification of facilities needed to treat and transport the supplies to the points of demand. As is often the case, this process was iterative and required the analysis of a variety of options for reliability. Finally, facility options may be group into three alternatives for water delivery based upon the origin of the supply and location of new facilities required to convey that supply. Each alternative will be evaluated according to established criteria, including cost (net present value), reliability, and qualitative criteria.

Fundamental to this planning process is the uncertainty of future conditions driving demand for water and the availability of supplies.

## 4.2 Assumptions

A number of assumptions had to be made, most significant of which were projections of future population and the geographic distribution of the population.

Using the principles of statistical theory, a reliability-based approach to forecasting that is the Least Square Approach and the Linear Trend time series statistical model were used for the quantitative methods to characterize the uncertainty or risk inherent in these assumptions.

A reliability-based approach allows facility options to be developed that specifically address the uncertainty inherent in large infrastructure planning.

The advantages to using a reliability-based approach are: 1) overly conservative designs that simply incorporate a peaking factor are minimized and 2) investment decisions can be made more easily that take into account both cost and reliability objectives.

The goal of a reliability-based approach is to give decision makers a range of reliability levels from which to choose. The costs of the alternative supply options, combined with the cost of the conveyance facilities to deliver the supplies, can be presented, along with the estimated level of reliability each option achieves. This allows facility investment decisions to be based not just on cost, but also on the level of reliability that is desire to be purchase.

The following section outlines the steps taken in a reliability-based approach to facilities planning.

**Water Facility Planning: a Reliability-Based Approach**

Water facility planning begins with projections of future demands, see table 4-2 below. Since demand estimation is the foundation on which facility planning is based, it is critical to invest significant effort in this first step. When developing supply and demand projections, there is always uncertainty about what will really happen in the future; as the planning horizon is extended further into the future, this uncertainty increases. Rather than adding safety factors to allow for the possibility that demands could grow at a rate faster than anticipated, a reliability-based approach uses methods to quantify uncertainty using a probabilistic analysis. *A probabilistic analysis focuses on the factors that drive the particular variable that is of interest. The variable of demand is driven by population, number of housing units, housing density, employment, location of water use (i.e., hot, dry versus cool, moist locations), type of use (e.g., agriculture, commercial, residential, ecological), and other factors*. The historical impact of these factors on demand is analyzed so that relationships between the factors and demand can be established.

The common practice in most water industry to address water demand estimation is the using peaking factors approach. This is usually done by observing past trends for water use and developing a percentage increase over normal demand that represents a high-demand scenario in warmer, drier years. Peaking factors estimate the maximum rate of flow, and are used as multipliers on the point forecast to estimate the maximum rate of flow. The maximum or peak flow rate is used to size facilities. *One of the problems with using peaking factors to reflect unusual, high-demand events is that there is no understanding of how likely it is for these events to occur.*

Without knowing the probability of high demand events occurring, it is difficult to ascertain the actual risk of not meeting demand and advise decision makers on the level of reliability that a particular facility or supply investment is providing. By using a probabilistic analysis, risk can be evaluated and expressed as the probability that water demands will exceed specified volumes. The magnitude by which water demand may exceed these volumes can also be given.

Because of Human, Economic and Climatic condition varying over time, planner, scientist, and Environmentalist, must find ways to keep abreast of the effects that such changes will have on the Environment, cities, and Human Economy community. One technique that can aid in the planning for the future hence sustainable development is accurately forecasting. Although numerous forecasting methods have been devised, they all have one common goal—to make predictions of the future events, such that the prediction can be incorporated into the planning and the strategically decision making. Though in making this prediction, one must take into consideration factors influencing time series data, there are four components to a time series: *the trend, the cyclical variation, the season variation, and the irregular variation.* See summary of these effect in the table below.

Table 4-1: Factors influencing Time series data

| COMPONENT | CLASSIFICATION OF COMPONENT | DEFINITION | REASON FOR INFLUENCE | DURATION |
|---|---|---|---|---|
| Trend | Systematic | Overall or persistent, long-term upward or downward pattern of movement | Changes in technology, population, wealth, value | Several years |
| Seasonal | Systematic | Fairly regular periodic fluctuations that occur within each 12-month period year after year | Weather conditions, social customs | Within 12 months (or monthly or quarterly data) |
| Cyclical | Systematic | Repeating up-and-down swings or movement through 3 phases: prosperity, population growth, recession. | Interaction of numerous combinations of factor that influence the economy | Usually 2-10 years, with differing intensity for a complete cycle |
| Irregular | Unsystematic | The erratic, or "residual" fluctuations in a series that exist after taking account of the systematic effects | Random variations in data or due to unforeseen events such as hurricanes, typhoids, floods | Short duration and nonrepeating |

The emphasis in this chapter is on the time series analysis and forecasting. A time series is a collection of data recorded over a period in time usually—monthly, quarterly, or yearly. An analysis of the past history—a time series---can be used by the management to make current decisions and for the long-term forecasting and planning towards sustainable development

In order to truly quantify the amount of water that will be Supply by the local community through the natural precipitation, and exploitation: the additional water Import from the neighboring water Channels and Rivers: and finally the Utilization capacity for the community given a specific period in time, The **LEAST SQUARE TREND FITTING AND FORECASTING METHOD** is applied in this case.

The Simple Linear Trend/Regression Model $Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$

Where $\beta_0$ = Y intercept for the population

$\beta_1$ = Slope for the population

$\varepsilon_i$ = Random error in Y for observation i

This is the simplest forecasting model; this forecasting model is given as

$\hat{Y}_i = b_o + b_1 X_i$

Sample slope and the $\hat{Y}_i$ intercept $b_0$, X can be substituted for time (year) to predict the value of Y.

The Linear Trend Model was arrived by this simple calculatable method

$$b_1 = \frac{n(\sum XY) - (\sum X)(\sum Y)}{n(\sum X^2) - (\sum X)^2}$$ And

$$b_0 = \frac{\sum Y}{n} - \frac{b \sum X}{n}$$

**X** is a value of the independent variable such as time (year)
**Y** is a value of the dependent variable such as the water supply, supply & import, utilization.
**n** is the number of the items in the sample.

Table 4-2: Predicted values using MINITAB for water planning for the year 2006 to 2030

Water Supply = 38456 +366(year)

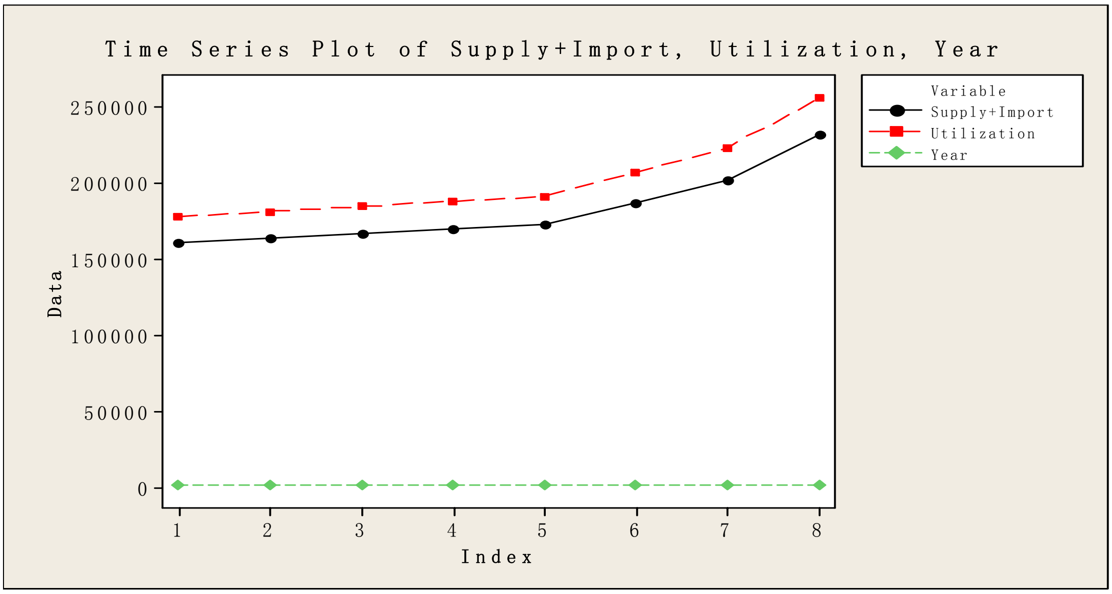
Supply & Import = 121821 +2966(year)

Utilization = 135985 + 3228(year)

Note: All value are in 10000 $m^3$ unit

| Year | Water Supply | Supply+Import | Utilization | Water Shortage | Shortage Coef. |
|---|---|---|---|---|---|
| 2006 | 43214 | 160379 | 177949 | -17570 | -9.87% |
| 2007 | 43580 | 163345 | 181177 | -17832 | -9.84% |
| 2008 | 43946 | 166311 | 184405 | -18094 | -9.81% |
| 2009 | 44312 | 169277 | 187633 | -18356 | -9.78% |
| 2010 | 44678 | 172243 | 190861 | -18618 | -9.75% |
| 2015 | 46508 | 187073 | 207001 | -19928 | -9.63% |
| 2020 | 48338 | 201903 | 223141 | -21238 | -9.52% |
| 2030 | 51998 | 231593 | 255421 | -23828 | -9.33% |
| TOTAL | 366574 | 1452124 | 1607588 | -155464 | -9.67% |

Note: that Water shortage = Water Utilization – (Water Supply + water Import)
Water Shortage Coeff = (Water Shortage/Water Utilization) X 100.




Though for ease calculation the Minitab Software application was use with 95% degree of confidence to predict the linear variable constant used for the prediction, also some analytical tool was also use to test for degree of fitness and accuracy in using this Simple Linear Progression.

The second step in the water facility planning process is the identification and characterization of supplies. Characteristics such as quantity, reliability, availability (including the location of the supply), cost, and quality are evaluated for each supply. Reliability can be expressed as the probability that certain quantities of water will be available in the future. That analysis can be based on several factors including weather and implementation constraints.
The third step is to develop facility configurations to store, treat, and deliver the various supplies to the points of demand. Existing facilities are analyzed first to determine if they are adequate to meet future demands. If the existing facilities are not adequate, then additional facilities are added to the system at the locations where the capacity is constrained. Since there may be a variety of ways to add facilities, several different configurations or facility options may need to be developed and compared.
Since there may be a variety of supply and facility options in a comprehensive planning effort, the process described above is usually iterative. This is because the factors that can alter the types of supplies will impact the facilities needed to deliver the supplies.

Table 4-3: Summarized table comparing MINITAB and WEAPs Software analysis in million $m^3$

| ITEMS | MINITAB | | WEAP | |
|---|---|---|---|---|
| | Annually | 2006-2030 | Annually | 2006-2030 |
| Supply | 497.06 | 11,901.50 | 786.00 | 19,650.02 |
| Importation | 1483.66 | 37,091.55 | | --- |
| SS + Import | 1959.80 | 48,995.05 | | --- |
| Demand | 2166.85 | 54,171.25 | 2206.24 | 55,156.02 |
| Population Growth Scenario | | --- | 2450.67 | 61,266.71 |
| Unmet Demand Given Import | 207.13 | 5,178.20 | | --- |
| Unmet Demand Without Import | 1690.79 | 42,269.75 | 1375.50 | 34,387.59 |
| Unmet Demand without Pop Grwt | | --- | 1559.34 | 39,983.49 |

Each simulation is driven by demand, that is, the monthly or daily demand of each member agency. The ability to meet that demand can be constrained by supply availability or by the capacity of the facilities to deliver supplies to meet the demand. In some cases, the delivery capacity constraint may be localized to a certain geographical area of the region. Though LEAST SQUARE TREND FITTING AND FORECASTING METHOD has it own limitations as it does not considering natural groundwater input, recharge, stream inflow, stream guage, reservoir conservancy e.t.c,. Hence we need to implore a more suitable model that takes into cognizant all the above listed factors for proper water prediction and management. Here we implore the use of WEAP (Water Planning And Evaluation System) developed in the United State of America. See table 4-3 for MINITAB and WEAP model comparison, the problem with MINITAB is that it only gives an upward trend of increases, this is because it relied only on the available data, it does not really simulate the real (project) case study area as in the case of using the WEAP Simulation model.

The following next Chapter describes the basic data used by WEAP simulation model and the steps followed to develop and analyze the model and facility alternatives.

# CHAPTER FIVE
# Application of WEAP Model

Modeling has become an essential tool in modern world of water management. It is used extensively and plays an important auxiliary role in fulfilling the core tasks of water management, in policy preparation, operational water management and research, and in the collection of basic data (monitoring), among other things. Besides the fact that the use of models is becoming increasingly common in water management, a development can also be discerned in items of increasing co-operation in the modeling field. The concept of a model is a very broad one; it is distinguished on the basis of the reason for the application, varying from policy analytical to scientific research models (detailed and narrow). Between the operational models (for real time control of structure, for example) and the calamity models, it is always possible to clearly distinguish between these fields. The model of WEAP intends to carry it simulation considering the various variable listed in figure 5-1, Final Conceptual Model framework, while figure 5-2 shows its overall water management procedures, considering demand, supply and infrastructural facilities.

**Post Fieldwork**

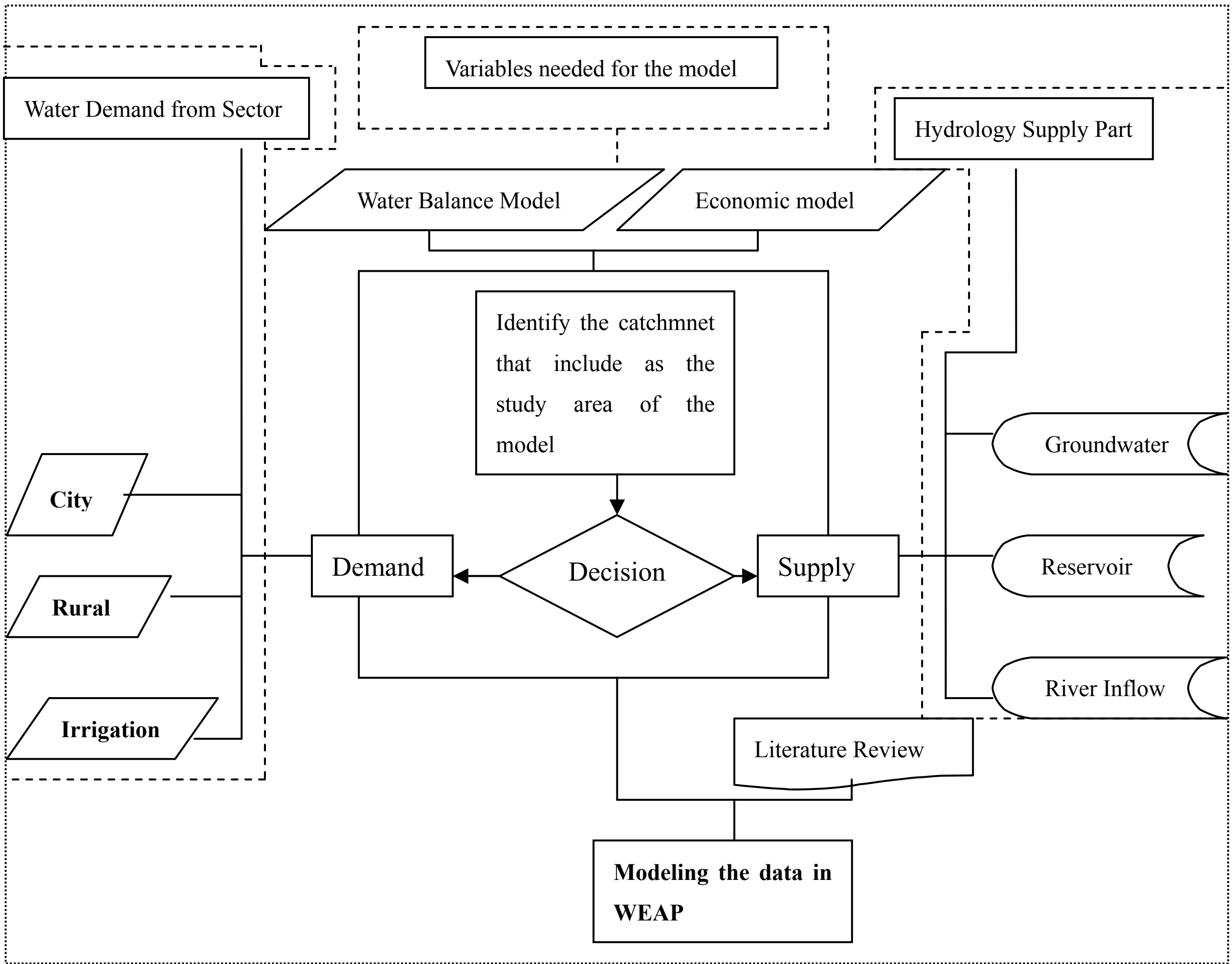



Figure 5-1: Final Conceptual Model

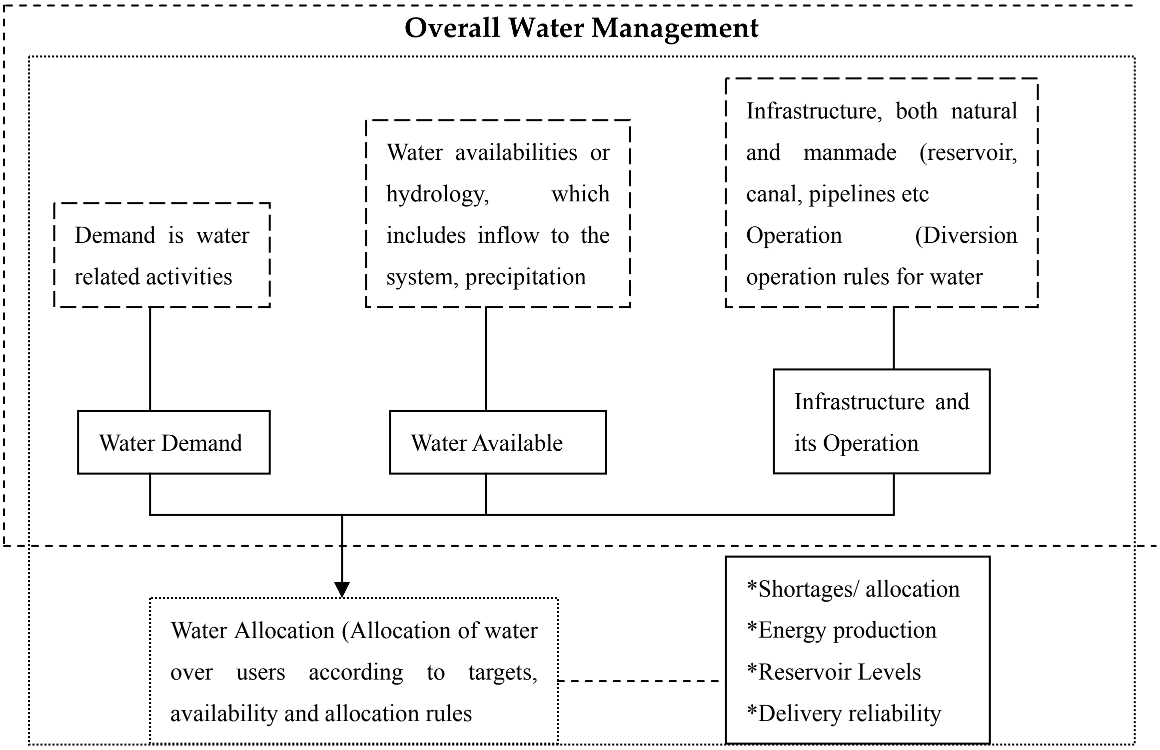



Figure 5-2: Schematic overview of ware management elements

## 5.1. Analytical framework: The Driving forces-Pressure-State-Impact-Response (DPSIR) Model of Heng Shui City Lake.

The most widely accepted indicator framework is the "Driving forces-Pressure-State-Impact-Response model" (DPSIR). The DPSIR model is an extension of the PSR (Pressure-State-Response) model, which was developed by Anthony Friend in the 1970s, and subsequently adopted by the OECD's State of the Environment (SOE) group. It defines five indicator categories Figure 5-3, Within the DPSIR framework; Eurostat (the Statistical Office of the European Communities) focuses on the Driving forces, Pressure and Response categories.
The Environmental Pressure Indices Project, conducted by Eurostat and financed by the European Commission's Environment DG, aims at a comprehensive description of the most important human activities that have a negative impact on the environment. The project reflects the efforts undertaken by the European Commission to provide decision-makers and the general public with the information necessary for the design and monitoring of an adequate environment policy for the European Union.( Jesinghaus, 1999)

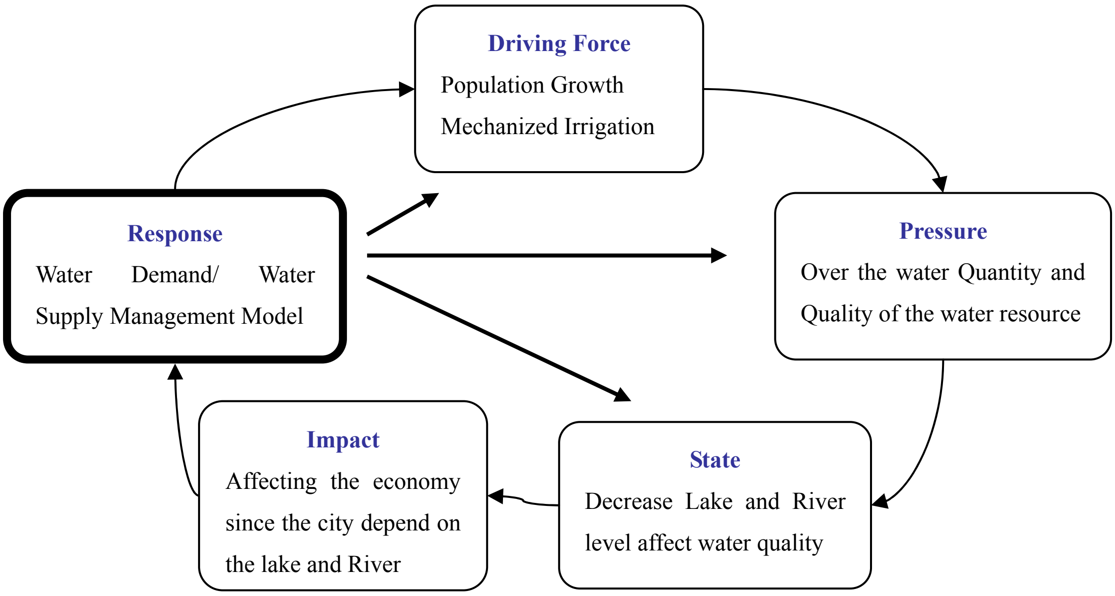



Figure 5-3: The Driving Force- Pressure-Impact- Response Framework Model for HS City.

**Driving force in HS City could be**

**1. Irrigation:** Agriculture creates pressure and stress on water resources through direct abstraction for Agricultural uses such as irrigation and watering of livestock, and by activities that are potentially polluting activities such as the use of fertilizers and pesticides.

Agriculture is thus the most important Driving Force in the sustainable management of water, and current activities and trends are outlined in this section.

**2. Population growth and urbanization**: Changes in population, population distribution and density are key factors influencing the demand for water resources.

**3. Industry and Climate change:** The driving forces in Heng Shui City produce a pressure on the quality and quantity of the water resources and deteriorate the state by lowering the river and lake level and influencing the economy and ecosystem of the catchment. Though 4% industrial water use were not considered in this model.

An adequate response to this situation is to develop an integrated water resource management model for the basin Figure 5-3. This would help in understanding and determining the real driving forces playing a role in the area.

## 5.2 Generalities and presentation of the WEAP model

The Stockholm Environment Institute (SEI) developed the WEAP model. It operates at a monthly step on the basic principle of water balance accounting. The user represents the system in terms of its various sources of supply (e.g. rivers, groundwater, and reservoirs), withdrawals, water demands, and ecosystem requirements.

WEAP applications generally involve the following steps (SEI, 2001):

•Problem definition including time frame, spatial boundary, system components and

configuration;
•Establishing the ‘current accounts’, which provides a snapshot of actual water demand, resources and supplies for the system;
•Building scenarios based on different sets of future trends based on policies, technological development, and other factors that affect demand, supply and hydrology;
•Evaluating the scenarios with regard to criteria such as adequacy of water resources, costs, benefits, and environmental impacts.

### 5.2.1 Scenario Analysis

With WEAP, first Current Account of the water system under study is created. Then, based on a variety of economic, demographic, hydrological, and technological trends a "reference" scenario projection is established, referred to as a Reference Scenario. Then one or more policy scenarios are developed with alternative assumptions about future developments.
The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir-operating rules are altered? What if water conservation is introduced? What if new sources of water pollution are added? What if a water-recycling program is implemented? What if a more efficient irrigation technique is implemented? What if ecosystem requirements are tightened? What if various demand management strategies is implemented?
What if climate change alters the hydrology? These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system.

An intuitive graphical interface provides a simple yet powerful means for constructing, viewing and modifying the system and its data. The main functions—loading data, calculating and reviewing results—are handled through an interactive screen structure. WEAP also has the flexibility to accommodate the evolving needs of the user: e.g. availability of better information changes in policy, planning requirements or local constraints and conditions.
The present application of the WEAP model forms part of ongoing research at the International Water Management Institute (IWMI) to develop, test and promote management practices and decision-support tools for effective management of water and land resources. WEAP has been described as being “comprehensive, straight forward and easy-to-use, and attempts to assist rather than substitute for the skilled planner” (University of Kassel, 2002).

### 5.2.2 Demand Capability and Management

WEAP represent the effects of demand management on water systems. Water requirements may be derived from a detailed set of final uses, or "water services" in different economic sectors. For example, crop types, irrigation districts and irrigation techniques could break down the agricultural sector, domestic water demand can be divided into single family, apartment and others, but in the case it was only single

family and others.
An urban sector could be organized by county, city, and water district. Industrial demand can be broken down by industrial sub-sector and further into process water and cooling water. This approach places development objectives--providing end-use goods and services--at the foundation of water analysis, and allows an evaluation of effects of improved technologies on these uses, as well as effects of changing prices on quantities of water demanded. In addition, priorities for allocating water for particular demands or from particular sources may be specified by the user.

Only the major water users were described (3 in total: some hundred irrigation schemes, 11 towns, and 1 big water reservoir). It is believed that when lumped together, their total demand could amount to a significant quantity. However, as will be shown later, neglecting this demand is a conservative assumption because any difficulty in satisfying the major water users will only be exacerbated by the addition of the minor users, driving home the need for even greater efforts on the demand management side.
For each major user, the activity level, the annual water demand (net values after accounting for losses), the monthly variation as well as a return flow (generally 90% for irrigation schemes in accordance with field survey observations in Heng Shui City) were introduced (see map. 1).
Growth rates between 1993 and 2030 were as follows: domestic 1.12-1.2 %, livestock 1.2 %, and irrigation 1.2%, also assumptive growth rate of 2.0 % was used.

### 5.2.3 Hydrology

In WEAP, rivers are considered to be made up of nodes connected by river reaches that have to be drawn. A river node has been introduced at the mouth of each quaternary basin as well as when a new tributary meets the Fu Dong Pai river. Naturalized monthly flows at each node were provided in an electronic format directly utilizable in WEAP, based on a study carried out of the hydrology of the Fu Dong Pai river basin. With 2 gauging stations including 2 on the Fu Dong Pai River, the hydrology is well described. One must note that the adjoining river sub-basin has been taken into account in WEAP as a flow entering directly into the system.
In WEAP, it is possible to quickly create different climatic situations ranging from very wet to very dry. Based on the analysis of nearly 100 years of observation (1920s– 2000s), the flow during the year 2006 was found to be the closest to the mean annual flow in the middle of the area, and was thus chosen as the year of reference.

### 5.2.4 Reservoirs

Generally, the operating strategies of the major reservoirs on the Fu Dong Pai River are to
1) Draw them down from late spring into early fall to meet the peak demand period and
2) Ensure adequate storage to capture the winter and early spring flood flows, while hydropower being a secondary benefit in most cases. To reflect these operational

objectives, reservoir-operating rules are expressed as monthly average reservoir volumes thresholds (table 5-13 and figure 5-56). These include a conservation volume above, which water is immediately passed downstream and within which water can be fully released to meet downstream demands. The next storage zone is called the *buffer zone* and defines a portion of the reservoir where system demands are restricted and downstream demands can only be met as a percentage (the buffer coefficient) of the available storage within the buffer zone. Below the buffer zone is the inactive storage that cannot be used to meet demands.

**5.2.5 Environmental Effects**

WEAP scenario analyses can take into account the requirements for aquatic ecosystems. They also can provide a summary of the pollution pressure different water uses impose on the overall system. Pollution is tracked from generation through treatment and outflow into surface and underground bodies of water. Moreover, WEAP addresses a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and stream flow simulations, reservoir operations, and hydropower generation and project benefit-cost analyses.

There are many case studies that are supported by WEAP Applications (Institute-Boston, 2003). In this thesis, water demand management is one of the options discussed in more detail. Once the basic reference scenario was developed, a series of simulations were investigated for diverse climatic situations from dry years to normal years in order to come out with conclusions.

## 5.3 Modeling Demand and Supply in WEAP:

The initial tasks in modeling with WEAP are to define the quantities of demand and supply of water. Modeling demand and supply using the WEAP software mainly depend on the current year that is defined as the starting year for the simulation. The characteristic of this “current year” is that it has all the available data for demand and supply, were the hydrological data (inflow, climatic, etc) as supply, and consumptions of all kinds as demand.

To start Modeling Demand and supply, the following must be identified:

-The Current Accounts represent the basic definition of the water system, as it currently exists. For this model the current account and the starting year for all scenarios were 1993 because the exploitation data availability.

-The last year of the model, this is 2030 in this case study

-The trend for simulation, which is how these data, will be modeled in WEAP and this will be defined for each component separately

Modeling in WEAP software was done using Heng Shui water balance data from 1965-2003 for the hydrology part. For the demand part mathematical expressions were used to allow the software to calculate different input parameters for the previous years.

The thesis focuses on the period between 1993 –2030 for scenario and analysis. This period was selected since the agricultural abstraction comprehensive and other data were available.

### 5.3.1 Scenarios Algorithm

**-Annual Demand in WEAP**

A demand site's (DS) was needed for water and it was calculated as the sum of the consumptions for all the demand site's bottom-level branches (Br). A bottom-level branch is one that has no branches below it.

$$\text{Annual Demand}_{DS} = \sum_{Br}(\text{Total Activity Level}_{Br} \text{ x Water Use Rate}_{Br}) \qquad (5\text{-}1)$$

The total activity level for a bottom-level branch is the product of the activity levels in all branches from the bottom branch back, up to the demand site branch (where Br is the bottom-level branch, Br' is the parent of Br, Br'' is the grandparent of Br, etc.).

$$\text{Total Activity Level}_{Br} = \text{Activity Level}_{Br} \text{ x Activity Level}_{Br'} \text{ x Activity Level}_{Br''} \text{ x} \qquad (5\text{-}2)$$

**-Monthly Supply Requirement**

The supply requirement is the actual amount needed from the supply sources. The supply requirement takes the demand and adjusts it to account for internal reuse, demand side management strategies (DSMS) for reducing demand, and internal losses..

$$\text{Monthly Supply Requirement}_{DS,m} = (\text{Monthly Demand}_{DS,m} \text{ x } (1 - \text{Reuse Rate}_{DS}) \text{ x } (1 - \text{DSMSavings}_{DS}))/(1 - \text{Loss Rate}_{DS}) \qquad (5\text{-}3)$$

**-Inflows and Outflows of Water**

This step computes water inflows to and outflows from every node and link in the system for a given month. This includes calculating withdrawals from supply sources to meet demand.

### 5.3.2 Inputs Parameters in WEAP

In order to define the inputs to the model the initial state and the tendency evolution of each input has to be entered. The Software allows the three methods to define the projection of the surface water hydrology over the study period. They are:

-**The Water Year Method:** It is an in-built model in WEAP that allows the predictions of hydrological variables based on the analysis of historical inflow data. It uses the statistical analysis to identify the coefficients, which is used to replace the real data for future projection.

-**Read From File Method:** If monthly data on inflows to some or all of the rivers and local supplies are available, then the Read From File Method allows the system to be modeled using this sequence of real inflows data. The required file formats for these data files is ASCII Data File Format for Monthly Inflows.

-**Expressions:** If any equation can explain the physical or evolutionary problem required in WEAP analysis, this equation can be entered.

**-Water Balance in Heng Shui Catchment (Supply)**

In order to build up the hydrological data explained in the previous paragraph, the supply and demand will be entered.

The supply input elements related to the water balance in the catchment were studied by Field data carried up to 2003. They were calculated based on monthly time steps for the period 1965 to 2003. A brief summary of the findings of this research follows:

The water balance model shows a very good correlation between its components and the observed lake levels. The model further shows that the ground water plays a crucial role in the water budget of the lake and an exchange of water between the lake and Groundwater. Groundwater outflow from the lake averages 30 million cubic meters per month. The water balance equation is:

$$\textbf{Lake volume change} = \textbf{inflow} + \textbf{rainfall} - \textbf{evaporation} \pm \textbf{Qaq} - \boldsymbol{Qout} \qquad \textbf{(5-4)}$$

Where Qaq; is the inflow to or out flow from a hypothetical dynamic ground water aquifer linked to the lake. It derives as:

$$Q_{aq} = c(H_{lake} - H_{aquifer})\ (m^3\ Month^{-1}) \qquad \textbf{(5-5)}$$

Where C is the hydraulic conductance of the aquifer ($m^2$ $month^{-1}$) and H is the water level (m). (Becht and Harper, 2002) The current model used the data from January 1965 to December 2003 obtained from Heng Shui City water balance model. Finally, the model manages to reproduce with his model the real River and lake fluctuations.

**-Model Discharge data for Heng Shui Lake used in WEAP**

**-Rivers**

The water balance model defines the inflow to the lake as a total. In order to disaggregate the inflow into real components, the average percentage discharge to the lake from the main rivers were taken.

This evaluation was decided after thorough analysis of discharge data carried out.

Total inflow to the lake from previous data from field survey to the year 2003 contributed to the lake by:

-70% from Fu Dong Pai River

-25% importation from River

-5% from other water tributaries to the lake

Under the above assumptions, 3 flow series were created for input in WEAP.

**-WEAP Input Data:**

The WEAP input data refers to the data that was integrated and used within the "WEAP" software.

**-River discharge**

River discharge refers to the process of entering the inflow discharge from rivers using the Expression and read from file and using the actual data. The input data was integrated as below;

-70% from Fu dong Pai River: ReadFromFile (inflow_2000.txt) * 0.4

-25% from Yellow River: ReadFromFile (inflow_2000.txt) * 0.4

-5% from other water tributaries: ReadFromFile (inflow_2000.txt) * 0.2
(inflow_2000.txt) refers to the text file that included the total inflow discharge from 1965 to December 2003

**-Net Evaporation data**

Reservoir Evaporation is the monthly evaporation rate. It accounts for the difference between evaporation and precipitation on the reservoir surface; thus it can be positive or negative. A positive (negative) net evaporation represents a net loss from (gain to) the reservoir.

It was also prepared in text file (ReadFromFile (NetEvap.txt)), which included the net-evaporation as in the water balance model of 2003.

**-Water Year Method in WEAP**

The Water Year Method allows use of historical data in a simplified form and exploration of the effects of future changes in hydrological patterns.

For example, we can use the Water Year Method to test the system under historic or hypothetical drought conditions. Hydrologic fluctuations are entered as variations from a Normal Water Year (the Current Accounts year is not necessarily a Normal water year). The Water Year Method requires data for defining standard types of water years (Water Year Definition), as well as defining the sequence of those years for a given set of scenarios (Water Year Sequence). A water year type characterizes the hydrological conditions over the period of one year. The five types that WEAP uses--Normal, Very Wet, Wet, Dry, and Very Dry--divide the years into five broad categories based on relative amounts of surface water inflows.

This part was developed using the actual data identified as the Wet, Normal, and Dry year to help in understanding the climate change in one scenario but was not used in the reference scenario. That depended on the actual data.

To build up the water year method, averages of the annual inflow for each year since 1965s to 2000s were determined and the minimum was taken as a very dry year and the maximum as very wet year, and then the normal year was mid point. Between the very Dry Year and the Normal Year there is a dry year. For the Normal year and the very wet year there is the wet year, as presented in Table 5-9

The definition factor defines each non-Normal water year type (Very Dry, Dry, Wet, Very Wet), and specifies how much more or less water flows into the system in that year relative to normal water.

## 5.4 The Heng Shui Lake

The Heng Shui Lake is an important tributary of the Fu Dong Pai River, contributing useful inflows of fresh water during critical periods; the Fu Dong Pai River itself is one of the reference (or benchmark) basins where the WEAP focuses much of its research effort in Heng Shui City. Map 1 shows the location of the Heng Shui Lake in relation to the Fu Dong Pai river basin and major counties in Heng Shui. Table 1 below summarizes the attributes of the city itself. Also map 1 show the main rivers and the quaternary basins, which are the basic hydrological units considered in this study.

### 5.4.1 Setting up the WEAP application for Heng Shui City

As mentioned earlier, data collection is a critical step in setting up WEAP. The characterization of the water system involved collecting and entering in WEAP the following data:

- Water uses (demand sites),
- Reservoirs: location, capacity and operation rules,
- Flow gauging station (flow requirement and ecological reserve),
- River headflows.

**-Socio economic development related to the water abstraction (Demand in Heng Shui catchment)**

Demand of water for domestic use, agriculture, household use, and industry continues to increase rapidly in the city. In this part the demand input data will be develop to be modeled in the software.

The WEAP software looked at the water balance as two parts, inflow and outflow, and computed water inflows to and outflow from every node and link in the system for a given month. This included calculating withdrawals from supply sources to meet demand.

After the validation of the city Supply part inside WEAP the Demand part in the city catchment was addressed as follows; Agriculture, population growth, domestic and the climate changes that put stress on the water availability.

**-Modeling demand in WEAP**

Demand analysis in WEAP is a disaggregated, end-use based approach for modeling the requirements for water consumption in an area. Using WEAP applying economic, demographic and water-use information to construct alternative scenarios that examine how total and disaggregated consumption of water evolve over time in all sectors of the economy. Demand analysis in WEAP is also the starting point for conducting integrated water planning analysis, since all supply and resource calculations in WEAP are driven by the levels of final demand calculated in the demand analysis.

WEAP provides flexibility in structuring data. These can range from highly disaggregated end-use oriented structures to highly aggregate analyses. Typically a structure would consist of sectors including households, industry and agriculture, each of which might be broken down into different subsectors end-uses and water-using devices. Structure the data to purposes, based on the availability of data, the types of analyses needed to conduct and unit preferences. The creating of different levels of disaggregation in each demand site and sector is very possible.

In each case, demand calculations are based on a disaggregated accounting for various measures of social and economic activity (number of households, hectares of irrigated agriculture, industrial and commercial value added, etc.). In the simplest cases, these activity levels are multiplied by the water use rates of each activity (water use per unit of activity). Each activity level and water use rate can be individually projected into the future using a variety of techniques, ranging from applying simple exponential growth rates and interpolation functions, to using sophisticated modeling techniques that take advantage of WEAP's powerful built-in modeling capabilities. More advanced approaches can incorporate hydrologic processes to determine demand (e.g. crop evapotranspiration calculations to determine irrigation requirements).

To model the demand in WEAP two main parameters has to be identified

1. **The Annual Activity level**: The annual demand represents the amount of water required by each demand. Losses, reuse, and efficiency are accounted for separately. Water consumption is calculated by multiplying the overall level of activity by a water use rate. Activity Levels are used in WEAP's Demand analysis as a measure of social and economic activity.

Activity levels for one of the hierarchical levels are typically described in absolute terms (in this case, the number of people in Heng Shui City is 4.13 million in the Current Accounts), while the other levels are described in proportionate (i.e., percentage share or percentage saturation) terms. In the example shown above, 75% of the population lives in single-family households in 1993. Notice that at the top level, the user chooses an absolute unit for the activity level (person). At lower levels, WEAP keeps track of the units, and hence knows that the percentage number entered at the second level is the share "of people". In general, WEAP lets you choose the numerator units for activity levels, while automatically displaying the denominator unit. When selecting an activity level unit, you can choose from any of the standard units. WEAP multiplies activity levels down each chain of branches to get a total activity. This depend on the modeled for each demand element and the data availability

2. **The Water Use Rate** is the average annual water consumption per unit of activity. WEAP displays the denominator (person, in the example below) to emphasize that this is a rate per unit, not the total amount of water used.

**-Population:**

The city is fast growing towns in Hebei province. The growth is fuelled by the increasing horticulture and floriculture farming business around Heng Shui Lake, rural to urban migration as a result of falling farm incomes from traditional cash crops, commercial enterprises and good job opportunities.

Population data was collected from various sources in the field and through several Internet demographic sources. Total population for the catchment and the surrounding areas of several years are shown in Table 5-1.

Table 5-1:Predicted Population growth of Heng Shui City

| % Growth | Year |
|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Heng Shui City | | 1993 | 2003 | 2006 | 2030 |
| Population (person) | 1.12% | 3,695,000 | 4,130,000 | 4,260,000 | 5,512,000 |
| Irrigation activity (Ha) | 1.2% | 390,000 | 439,500 | 455,512 | 601,324 |

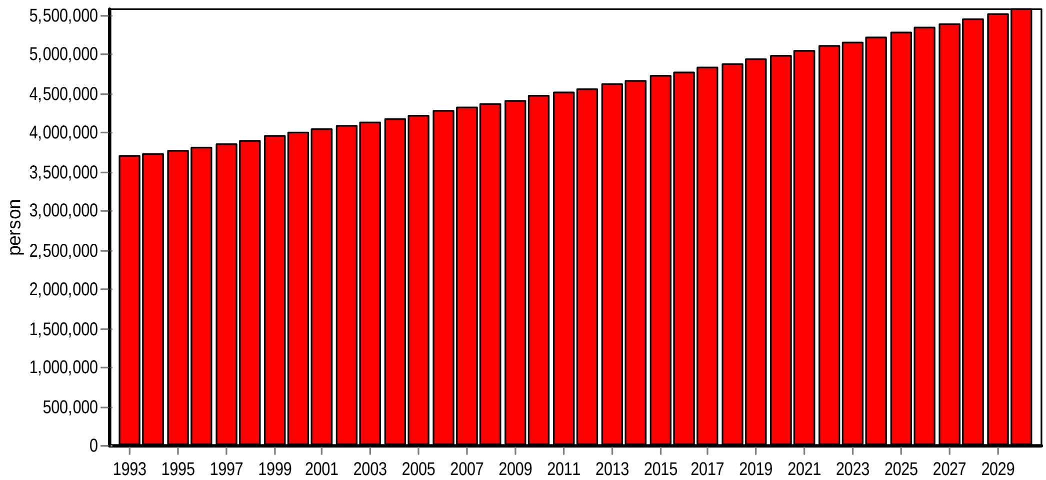



Figure 5-4: Predicted expected population growth using a rate of 1.12%

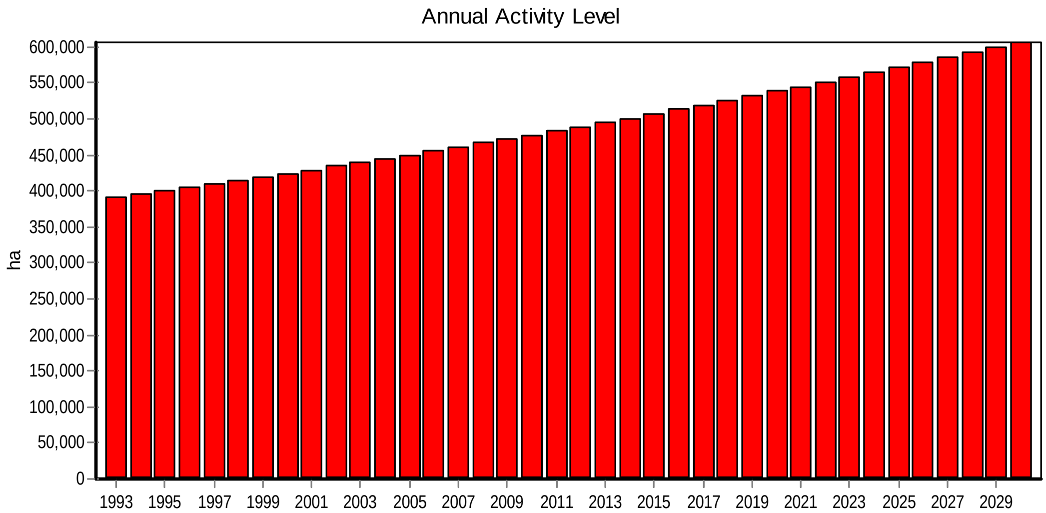



Figure 5-5: Predicted expected irrigation growth using a rate of 1.2%

The population of the towns and villages that affect the lake water level has been calculated backwards, using WEAP, for the period 1993-2030 using both the linear interpolation and the census growth rate. The population modeled is provided in Table 5-1, Figure 5-4 and 5-5.

The population demand for water was estimated according to field observation and personal interview with residence and from municipal council. This assumption varies according to the activities in the rural area and the city centre.

To calculate the population's total consumption, the population per area was multiplied by the amount of water per person per year and finally consumption of all the towns and villages was added.

**-Irrigation**

Agriculture in the Heng Shui catchment is one of the most important economic activities; it is the driving force in the area and has a high irrigation water demand. Plant and vegetable farming are leading the regional economy with yearly turnover of $10 million US. Different types of irrigation practices are used in the area such as pivots, dripping and sprinkling. Large farms have started using new technologies such as hydroponics soils, which recycle the water and, saves 30% of the applied water. It also increases the productivity and reduces the area of cultivated land.

WEAP software farm input data requires two main parameters to be identified; 1) the area of cultivation and 2) the annual water use for each crop.
1) This parameter in WEAP corresponds to the *Annual Activity Level,* shows the data entered into WEAP as the total area of farms. The calculation was made as ratio in percentage form within the different years, which in this case is 439,500Ha.
2) This parameter in WEAP corresponds to the *Annual Water Use Rate*. Applied irrigation and efficient irrigation values, shown in Table 5-2, were used as input in the different scenarios.

**-Treatment Plant**

The city can only boost of one Waste Water Treatment Plant designed the existing Heng Shui City sewage system. The WWTP was designed for a population of 4,000,000 people, was expected to serve about 5,000,000 people by 2030, and based on the projected figures established by the WEAP computation. The system designed for sewage treatment offering, 70% biochemical oxygen demand (BOD) removal and killing of more than 99% of bacteria according to Heng Shui sewage project preliminary design report.

The Heng Shui WWTP was designed with the following daily capacity utilization efficiency, Consumption rate 5%, Daily input Capacity of 80,000 $m^3$, BOD Removal rate 70%, DO Removal rate 67%, TSS Removal rate 75%, Salt Removal Rate 20% and it internal temperature of 15$^o$C. Also irrigation water reuse rate were computed using the smooth interpolation curve. Smooth (1994,7; 1998,14, 2003,20; 2010,25; 2015,28, 2020,32; 2025, 36, 2030,40) and a value of 20% water losses were also computed.

Table 5-2: Past inputeddata use to calculate the water resource demand for the period 1993-2003

| Reference Account | 1993-2003 | |
|---|---|---|
| Population | 4.13 Million. | |
| Demand Site Uses | Heng Shui City Water uses | Heng Shui Irrigation |
| Annual Activity Level | 413 Million | 439500 |
| Annual Water Rate | 23.9 | 3115 |
| Consumption Rate | 20% | 95% |

Table 5-2a: Monthly River Headflow and Irrigation Variation data use to calculate the water resource demand for the period 1993-2003

| Months | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River | Headflow | 10 | 6 | 5 | 14 | 93 | 126 | 68 | 54 | 40 | 20 | 3 | 5 |
| Irrigation | Variation | 0% | 0% | 0% | 3% | 10% | 10% | 20% | 27% | 25% | 5% | 0% | 0% |

Table 5-2b: Comparing Actual and WEAP application Modeling Software for validity in 10,000m$^3$

| ITEMS | ANNUAL AVERAGE | TOTAL 1993-2003 |
|---|---|---|
| WEAP COMPUTATION | 1,520,97.1582 | 16,730,68.7402 |
| ACTUAL OBSERVATION | 1,521,26.6000 | 16,733,92.6000 |
| DIFFERENCES | 29.4418 | 3,23.8598 |
| The differences may result from water loss of evaporation not incorporated in the actual computation | | |

## 5.5 Schematic maps showing the maximum annual water consumed or Demand

*Figure 5-6: Location of the study area in Heng Shui City and. the maximum annual water consumed or Demand for Irrigation and City Domestic uses for 1993-2003 periods, in million m$^3$.*

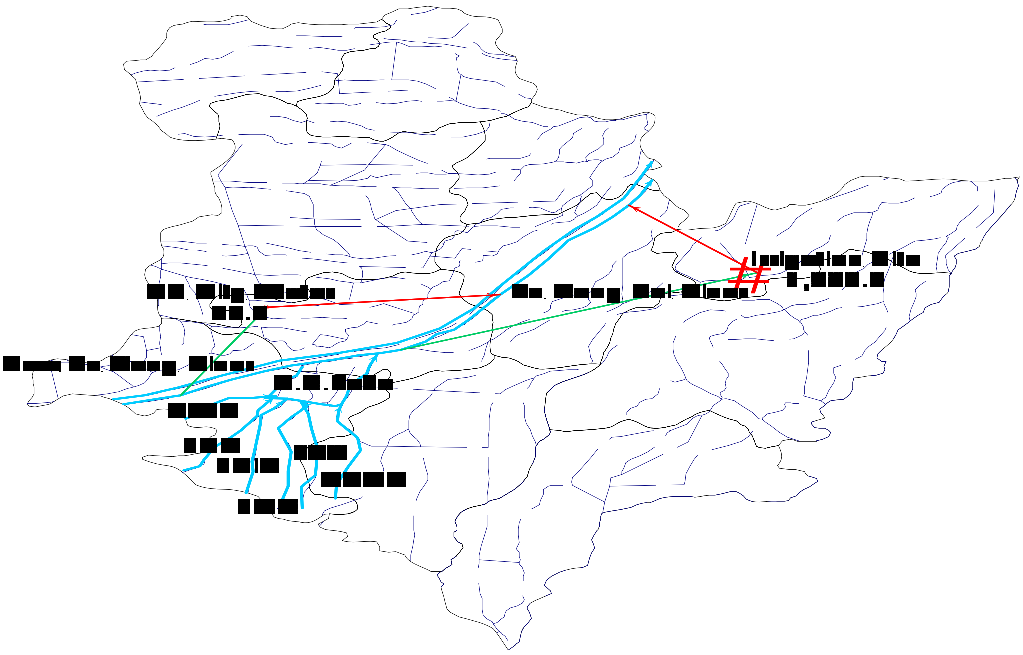


Table 5-3: Average monthly Water Demand and Unmet demand in million m$^3$ (1993-2003)

| Month | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| City | Demand | 8.4 | 7.6 | 8.4 | 8.1 | 8.4 | 8.1 | 8.4 | 8.4 | 8.1 | 8.4 | 8.1 | 8.4 | 99.1 |
| Usage | Unmet | 0.0 | 0.0 | 0.0 | 2.1 | 0.0 | 0.0 | 3.0 | 5.2 | 5.7 | 2.6 | 0.4 | 0.0 | 19.0 |
| Irrigation | Demand | 0.0 | 0.0 | 0.0 | 41.1 | 136.9 | 136.9 | 273.8 | 369.6 | 342.3 | 68.5 | 0.0 | 0.0 | 1369.1 |
| | Unmet | 0.0 | 0.0 | 0.0 | 10.8 | 0.0 | 0.0 | 97.1 | 228.2 | 241.0 | 20.8 | 0.0 | 0.0 | 597.9 |
| Total Demand | | 8.4 | 7.6 | 8.4 | 49.2 | 145.3 | 145.1 | 282.2 | 378.1 | 350.4 | 76.9 | 8.1 | 8.4 | 1468.2 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Unmet Demand | 0.0 | 0.0 | 0.0 | 12.9 | 0.0 | 0.0 | 100.1 | 233.4 | 246.7 | 23.3 | 0.4 | 0.0 | 616.9 |

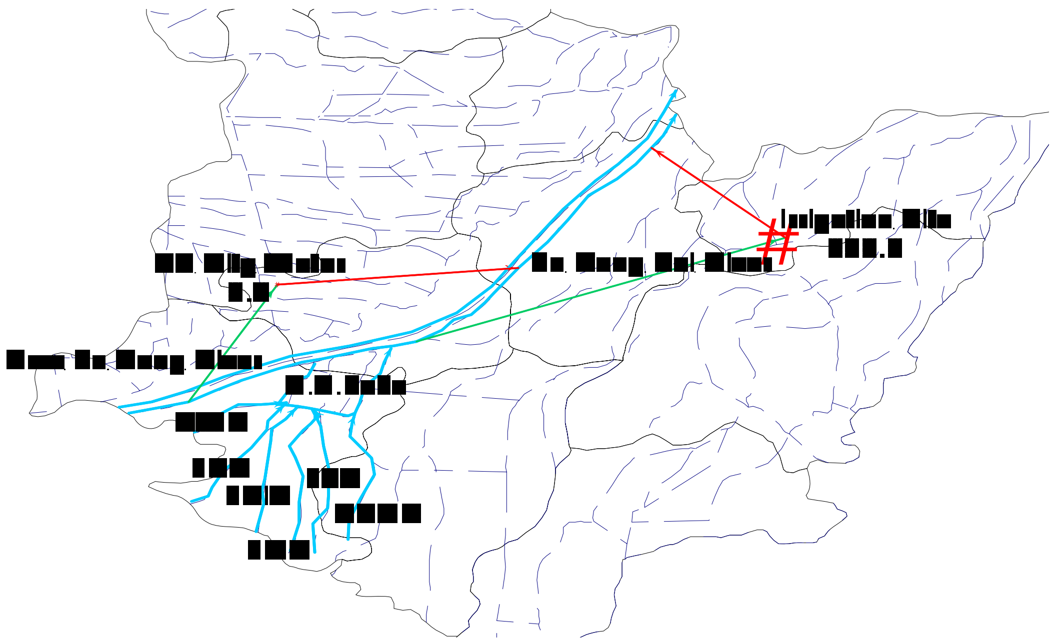


*Figure* 5-7: The highest monthly (August) average values, for Irrigation and HS city usage water demand.

Monthly Average 369.6 and 8.4 million $m^3$ of water demanded for Irrigation and city water use respectively.

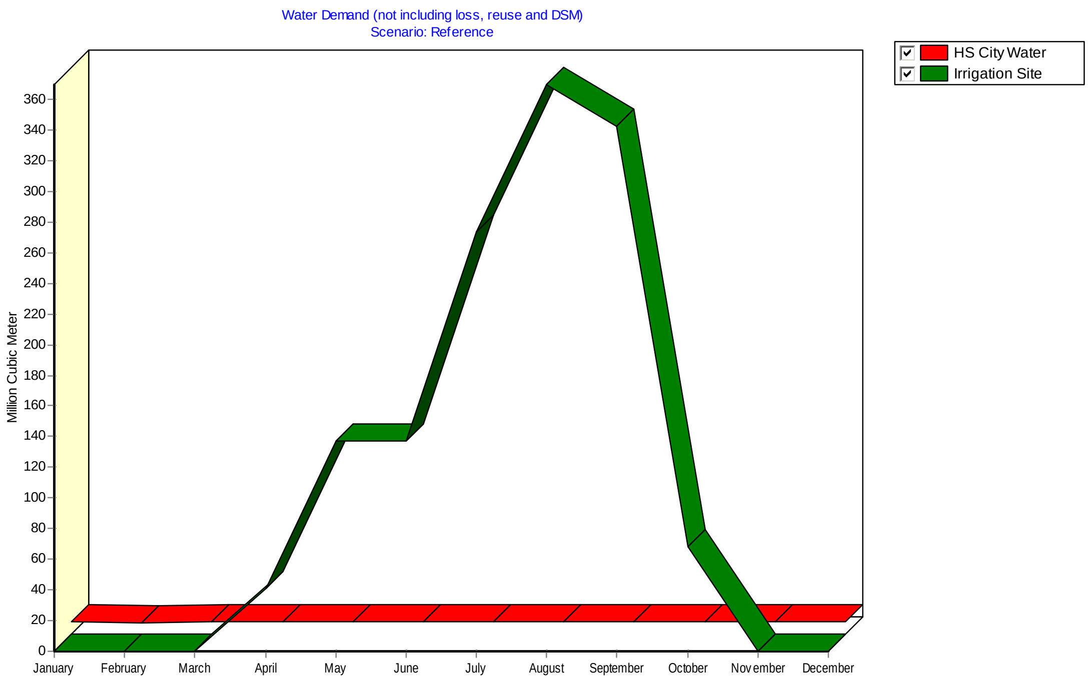



*Figure* 5-8: Monthly water demand for each year in million $m^3$.

The City water demand was constant because there was no variation input to the computation. Also as we can compute the water demand coverage with and without monthly variation, for the city using the WEAP Model, see *Figure* 5-9 and 5-13 below were the graphical illustration to this respect. During the months of November and March, except for domestics' water, which have little flow in the river, HS city lack water, and therefore demands go unmet. Irrigation only has a shortfall in supply in the month of July to September, when the plants require most water (*Figure 5-10)*, also see Table 5-3), While *Figure* 5-13 show full demand coverage for HS City, especially for the month of December, specifically when Domestics Variation was computed.

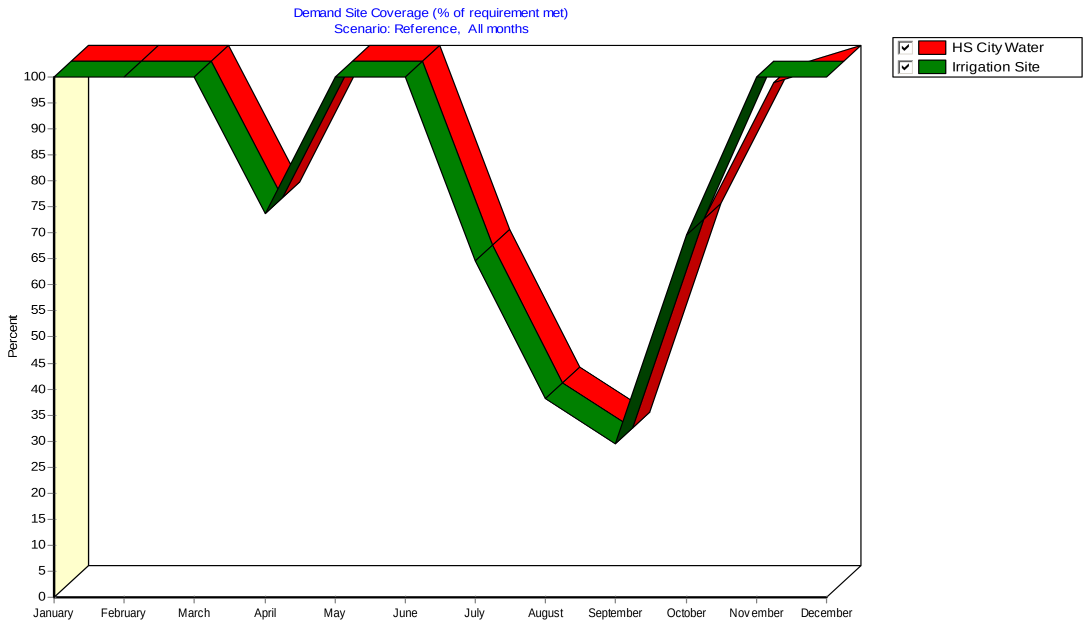



*Figure* 5-9: Monthly percentage water demand coverage for each year

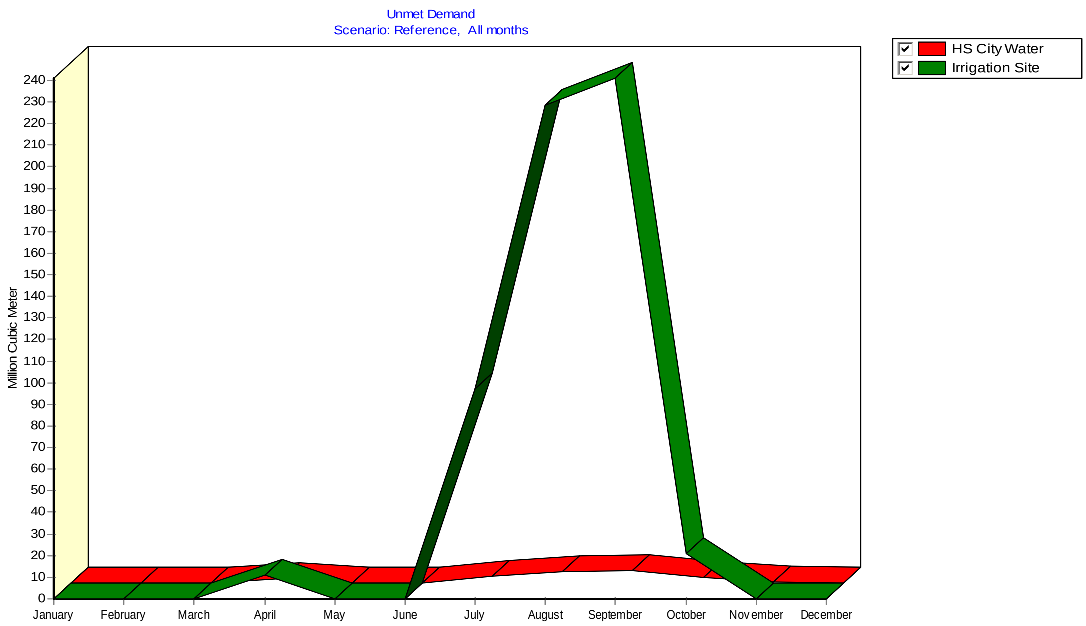



*Figure* 5-10 Monthly unmet water demands for each year in million $m^3$.

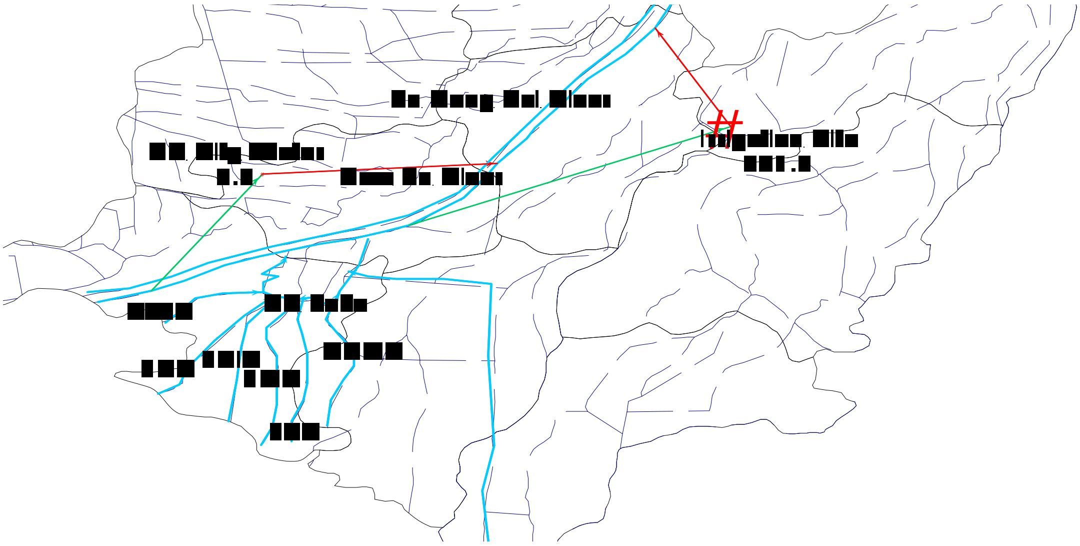


*Figure* 5-11: The highest average monthly (September) Unmet water demand values, for Irrigation and HS city.

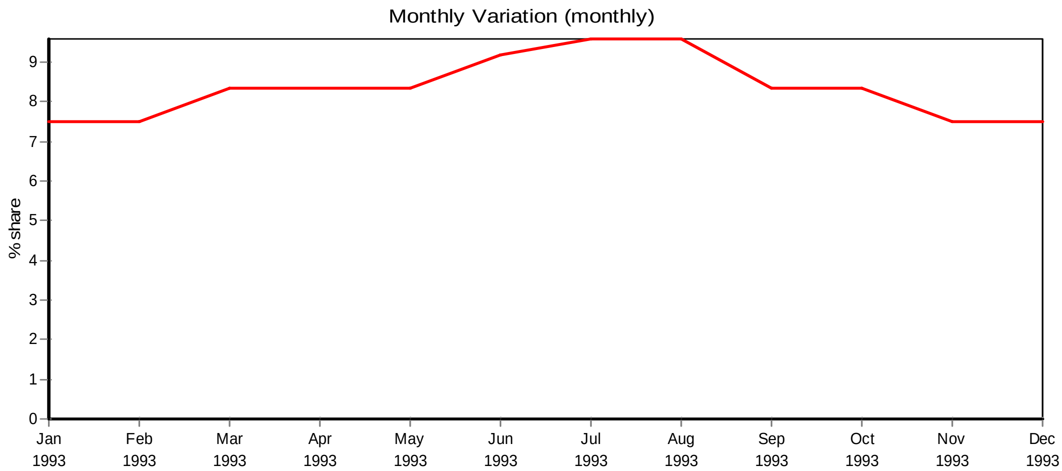



*Figure* 5-12: Monthly domestic water variation inputs.

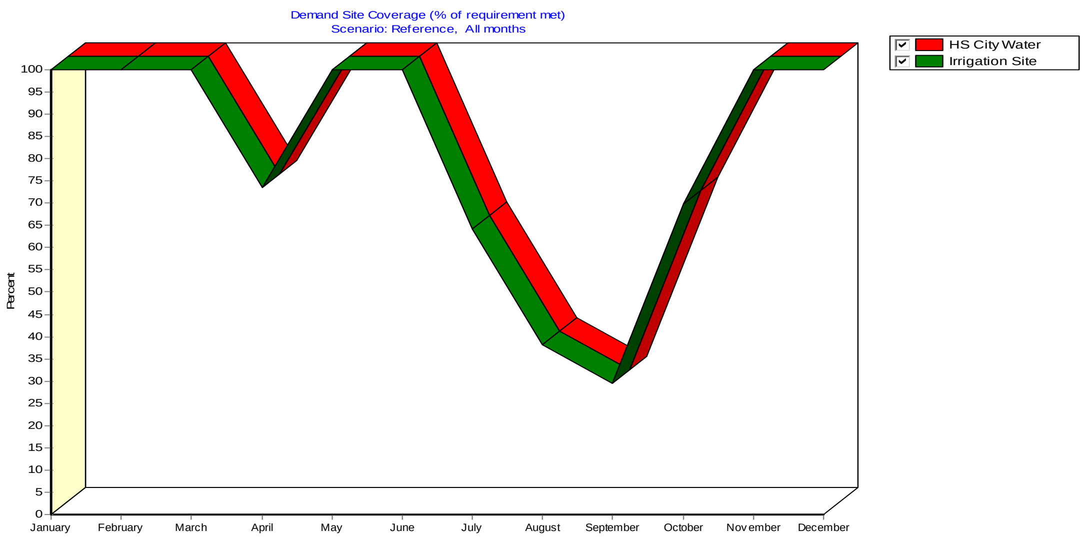



*Figure* 5-13: The Influences domestic variation data on Monthly water demand coverage.

Note that there now is no unmet demand in December for HS City because the fraction of demand in December decreased from 9.6% (originally based on the number of days in the month) to 7.3% (now based on the expression using the Domestic Variation). Used in the key assumption.

### 5.5.1 CREATING REFERENCE SCENARIOS FOR A PERIOD FROM 1993-2030

### A) WORKING WITH SCENARIOS

**-Scenarios Development and Management**

Water sustainability assessment requires a scenario approach for taking a long wide view that considers futures with fundamentally different development and environmental assumptions and policies. Using integrated water management scenarios, diverse stakeholders can engage in informed dialogues around balancing trade-offs and devising appropriate actions.

In this Chapter different scenarios built using WEAP as software are discussed. In WEAP the basic model was built using the real data to be used for scenario management and analysis Table 5-6.

Develop a scenario, to propose a certain set of management actions to be implemented with the objective understanding the effects of different elements that affect the lake level and what options to improve the management in the lake through integrated water resource management.

**-Reference Scenario (1993 – 2030)**

The reference scenario is the base scenario that uses the actual data, to help in understanding the best estimates about the studied period.

The objective of a reference scenario is to help planner and water resource manager understand what likely could occur if current trend continue and to understand the real situation. Reference scenarios can also be useful for identifying where knowledge is weak in analysing likely trends and where more information needs to be collected. They can be useful for designing contingency plans where there is a lot of risk and uncertainty.

In this study the basic model has been build using WEAP; reflects the Reference scenario, which replicates the real situation.

**- High Population Growth Scenario (1993-2003)**

The following results were obtained from the Actual Situation (reference) scenario:

Table 5-4: Annual percentage increase on city and overall total water demands as a result of higher population growth (1.12 to 2.0%) and Irrigation efficiency (1993 to 2030).

| | Scenario | Water Demand | % Increases | Unmet Demand | % Increases |
|---|---|---|---|---|---|
| City Water Use | 1.12% Pop Growth | 22,569.9 | 27.07 | 12,450.8 | 37.32 |
| | 2.0% Population Growth | 28,680.6 | | 17,097.6 | |
| All Demand | 1.12% Pop Growth | 71,886.7 | 8.50 | 35,506 | 15.76 |
| Total | 2.0% Population Growth | 77,997.4 | | 41,101.9 | |

The result show the effect of increased population growth on the water demand, the effect is much more visible on the population, unlike the water demand and unmet demand for Irrigation purpose, evident to say that the city water usage water demand and Unmet water demand percentage increase were higher with 27.07%, 37.32% against 8.50%, 15.76% of the overall city water variable respectively. See table 5-4 and Figure 5-14 to 5-21.

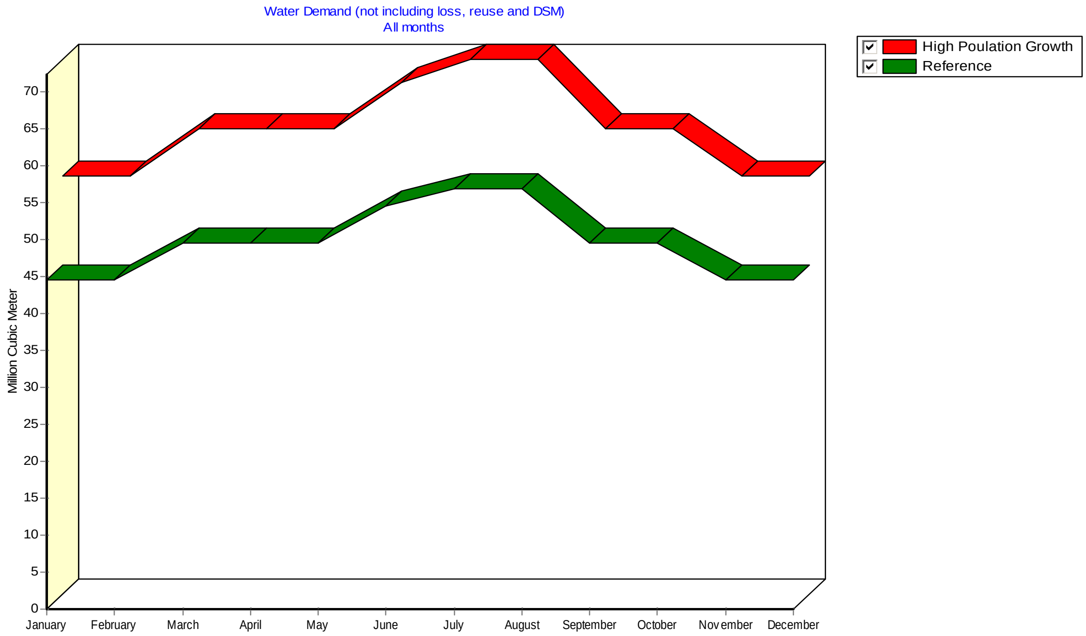



Figure 5-14: The effect of increase population growth on Monthly city water demand in million m$^3$.

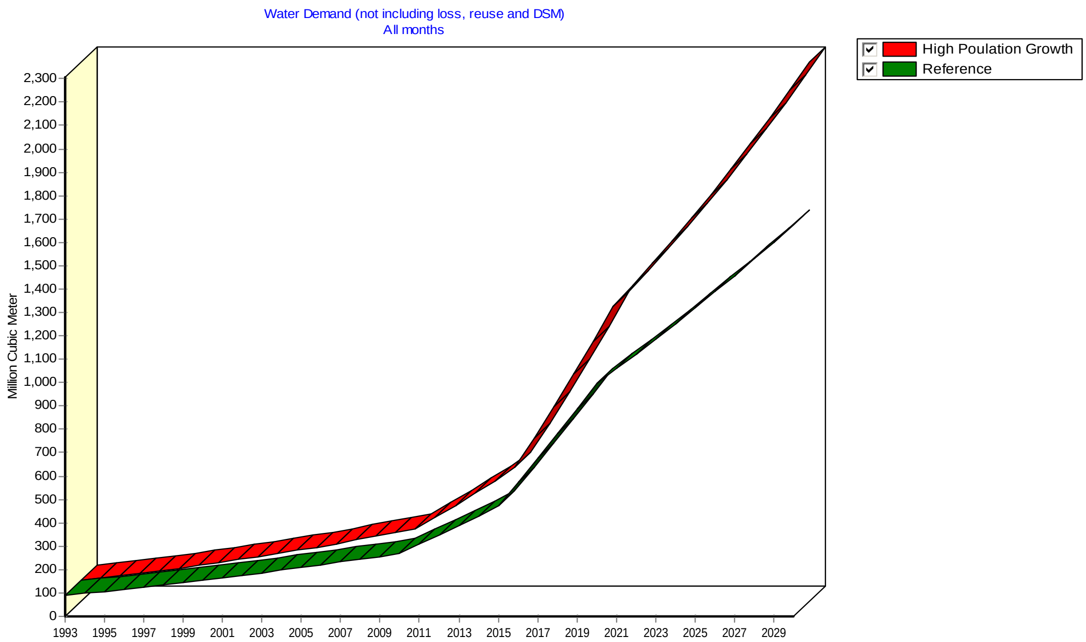



Figure 5-15: The effect of population growth on annual city water demand for1993-2030, in million m$^3$.

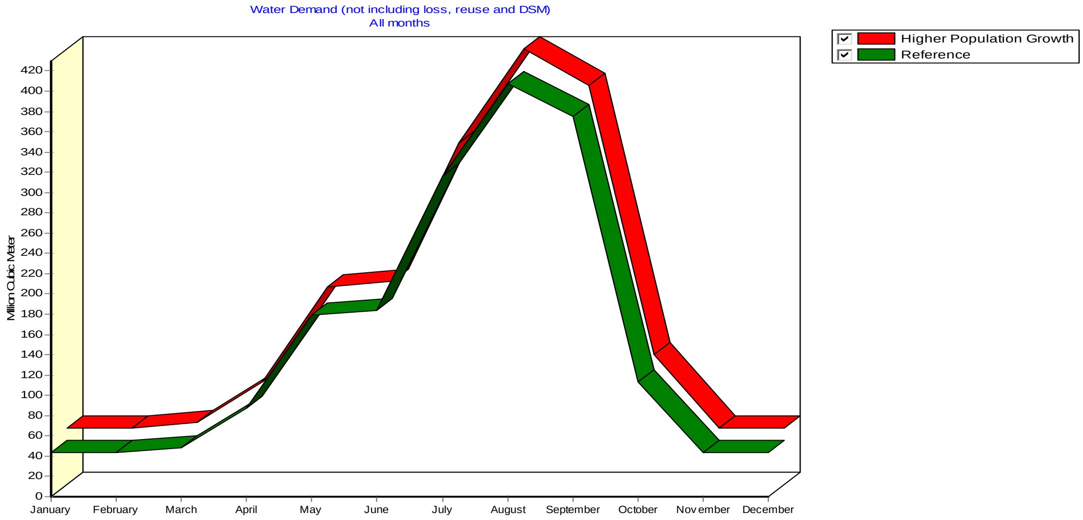



Figure 5-16: The effect of population growth on the monthly overall city water demand in million $m^3$.

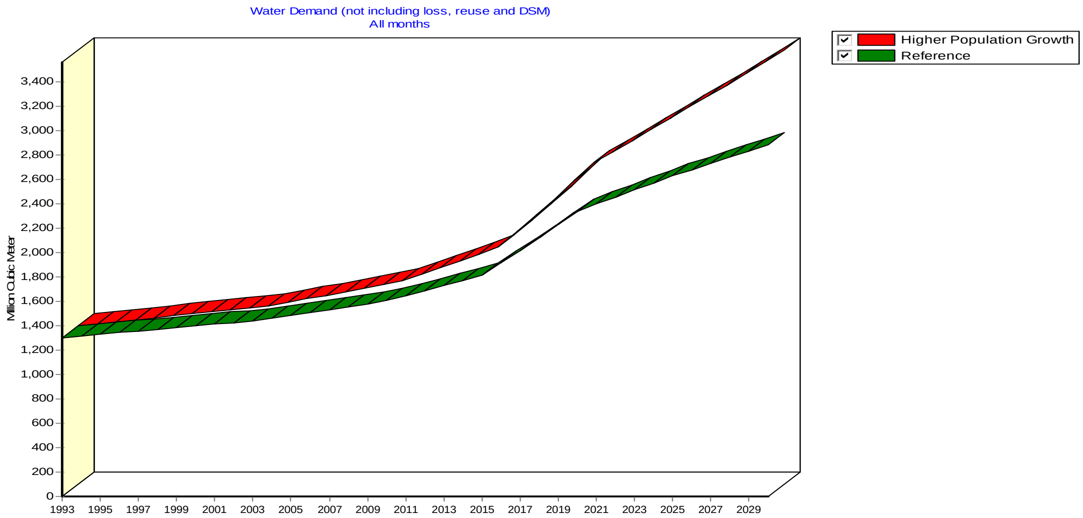



Figure 5-17: The effect of population growth on annual Overall city water demand for1993-2030, in million $m^3$.

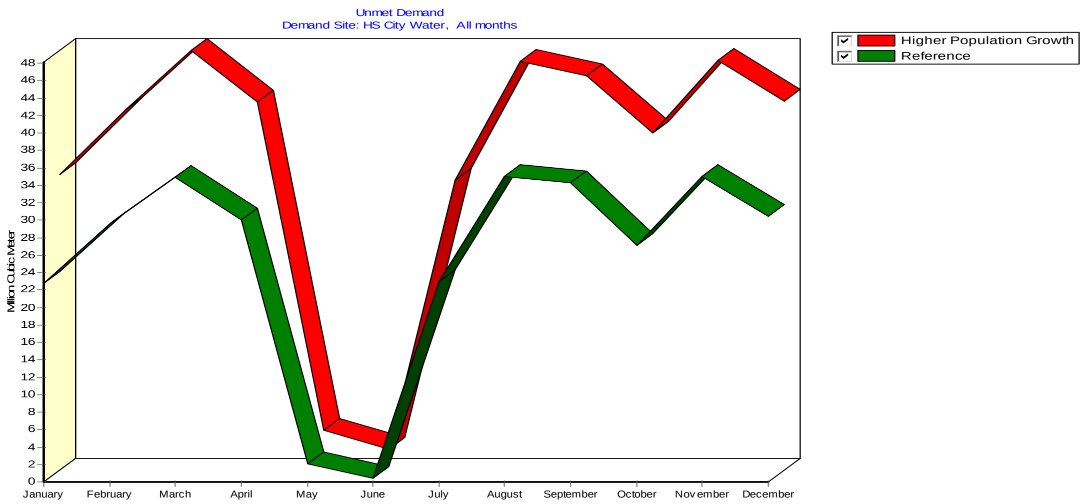



Figure 5-18: The effect of population growth on average monthly city unmet water demand in

million m$^3$.

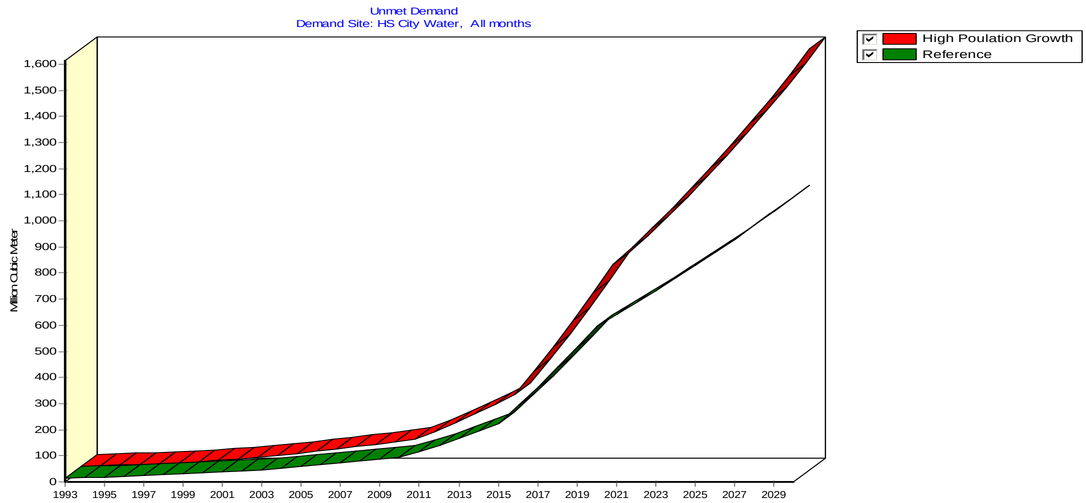



Figure 5-19: The effect of population growth on annual city unmet water demand in million m$^3$.

Table 5-5: monthly percentage increase on overall unmet water demand as a result of higher population growth (1.12 to 2.0%) for the Reference period (1993 to 2030). in Million m$^3$

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.0% Pop Grwt | 33.9 | 41.4 | 48.1 | 61.2 | 8.7 | 4.2 | 132.8 | 267.5 | 277.6 | 68.4 | 47.0 | 42.2 | 1,033.1 |
| 1.12% Pop Grwt | 22.8 | 29.6 | 35.0 | 47.2 | 4.3 | 0.9 | 112.8 | 245.7 | 258.3 | 53.9 | 35.0 | 30.5 | 875.9 |

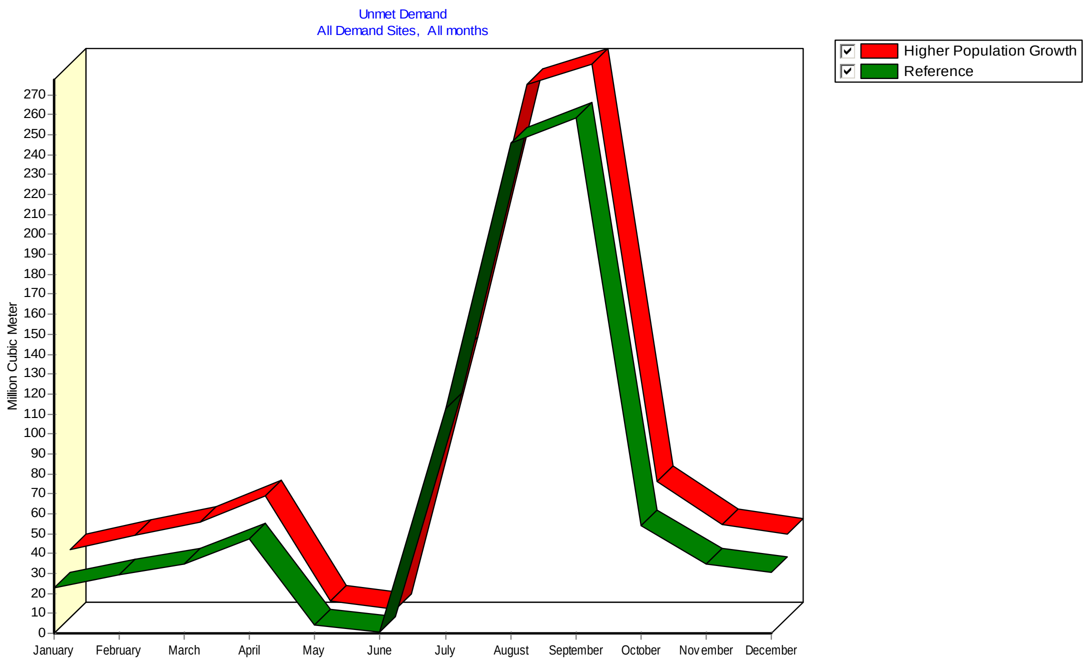



Figure 5-20: The effect of population growth on monthly average overall city unmet water demand in million m$^3$.

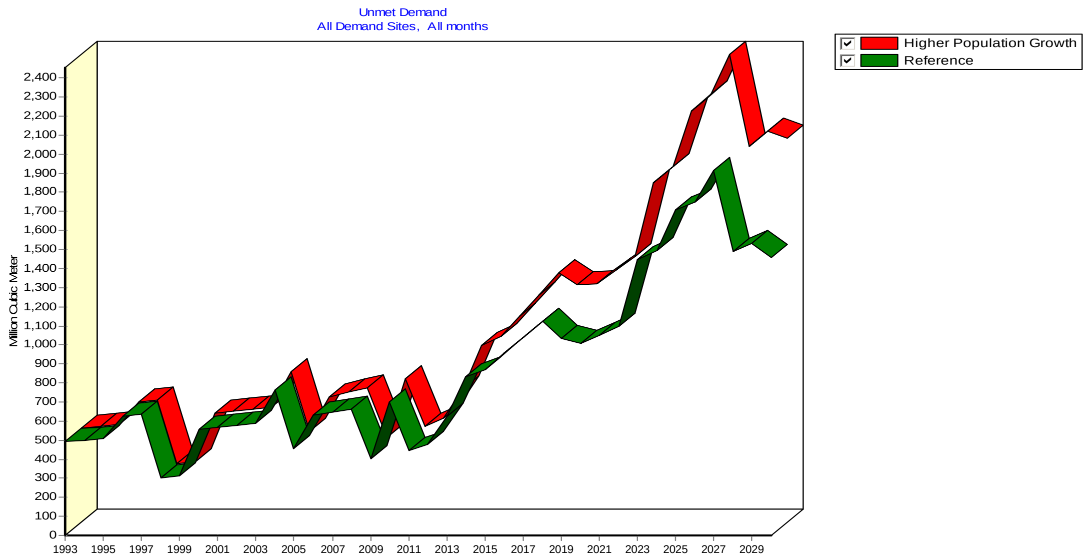



Figure 5-21: The effect of population growth on annual overall city unmet water demand in million $m^3$.

**-Efficient Irrigation Scenario**

The efficient irrigation is how much of the water that is applied is actually retained within the effective plant root zone in an irrigation event (data already computed, see table 5-6 below). By "applied" we mean water leaving the nozzle of a pressurized system, or passing over the sill for border-strip systems (Environmental, 2000).

The main water use in the agricultural sector is for irrigation, with minor contribution to the water demand of live stock farming and fish farming. Irrigation is the subject of this scenario, even though in certain areas livestock watering can also represents a significant demand.

To calculate the effective applied irrigation we will consider the efficiency of the irrigation. In this scenario we are going to apply our result to see the effect in the lake level and River Fu Dong Pai respectively.

The formulae below is use to calculate Irrigation water uses.

$$PercentageOfOverIrrigation = \left( \frac{Crop\,Requirement}{AppliedIrrigation} - 1 \right) X100 \qquad 5\text{-}6$$

**-High Technology Scenario**

According to the Field observation there were lots of water lost in irrigation and this water mostly goes back to the lake with some added chemical of pesticide and fertilizers that are used in the cultivation. Few farmers started applying the idea of new reservoirs to collect surplus of water from the irrigation.

Others use Hydroponics soils, which reduce water use when recycled but if the water is wasted, and then it soaks more water than the soil. By recycling, the water can be saved by 50 %, personal communication with farmers. Water reuse, water losses and WWTP were also discussed earlier in chapter 5.5.2.

Table 5-6: Changing water rate for Irrigation and City use because of improved technology.

| Year | 1993 | 2003 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Irrigation Water Use Rate ($m^3$/Ha) | 3115 | 3000 | 2800 | 2650 | 2500 | 2300 | 2000 |
| HS City Water Use Rate ($m^3$/Year) | 24 | 35 | 60 | 100 | 200 | 250 | 300 |

Table 5-7: The effect of population growth and slight improved irrigation technology on average monthly Water Demand and Unmet demand in million $m^3$ (1993-2030).

| Month | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| City | Demand | 44.5 | 44.5 | 49.5 | 48.3 | 49.5 | 54.4 | 56.9 | 56.9 | 49.5 | 49.5 | 44.5 | 44.5 | 593.9 |
| Usage | Unmet | 24.4 | 31.3 | 36.8 | 32.8 | 0.3 | 0.0 | 27.6 | 38.5 | 36.9 | 30.2 | 36.8 | 32.1 | 327.7 |
| Irrigation | Demand | 0.0 | 0.0 | 0.0 | 38.9 | 129.8 | 129.8 | 259.6 | 350.4 | 324.5 | 64.9 | 0.0 | 0.0 | 1297.8 |
| | Unmet | 0.0 | 0.0 | 0.0 | 19.4 | 0.3 | 0.0 | 106.8 | 224.2 | 233.4 | 30.6 | 0.0 | 0.0 | 614.6 |
| Total Demand | | 44.5 | 44.5 | 49.5 | 88.4 | 179.3 | 184.2 | 316.5 | 407.3 | 373.9 | 114.4 | 44.5 | 44.5 | 1891.8 |
| Total Unmet Demand | | 24.4 | 31.3 | 36.8 | 52.1 | 0.6 | 0.0 | 134.4 | 262.7 | 270.3 | 60.8 | 36.8 | 32.1 | 942.3 |

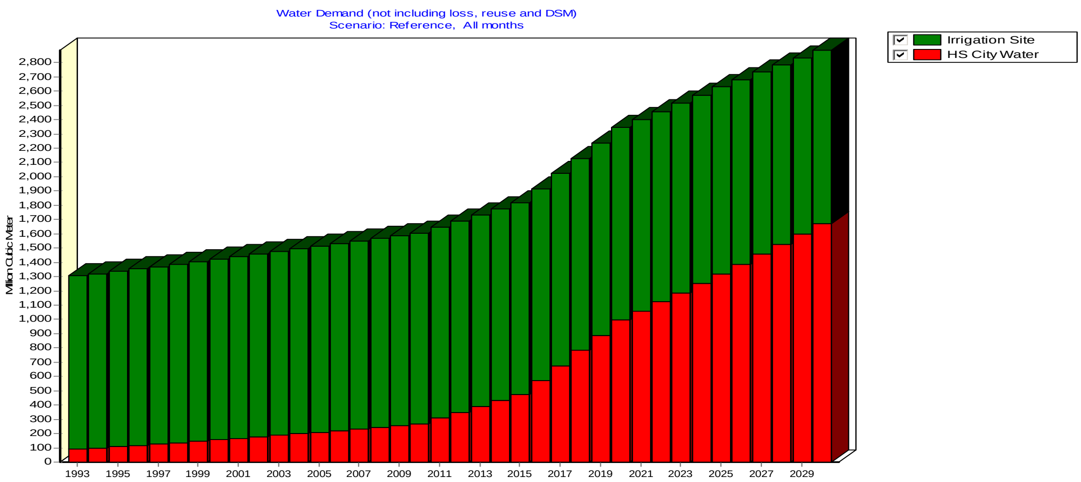



Figure 5-22: The effect of improved technology and irrigation efficiency shows annual increasing rate of water demand for both demand site in million $m^3$

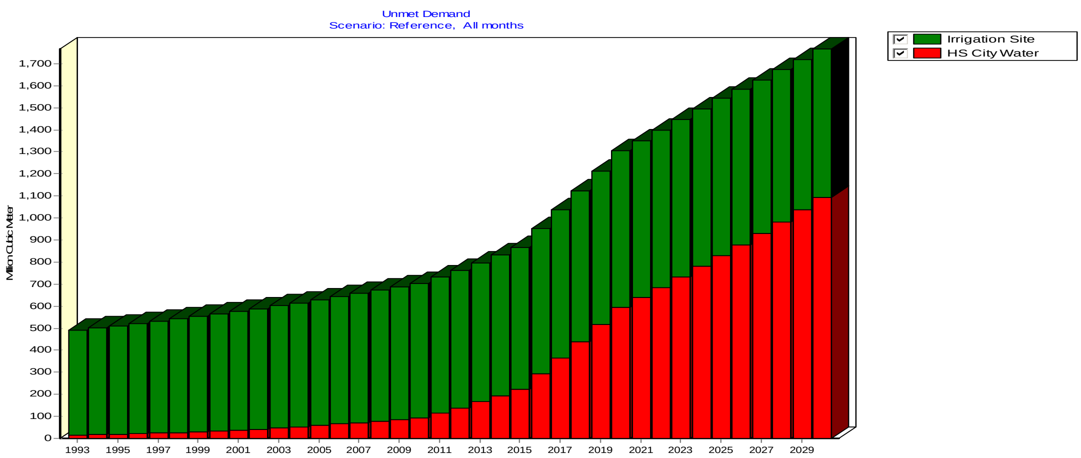



Figure 5-23: The effect of improved technology and irrigation efficiency shows an annual increasing rate of unmet water demand for both HS City and irrigation efficiency in million $m^3$

A) Table 5-7, depict the scenario for Improved Irrigation efficiency as a result of improved in technology, this improved technology reduce substantially water demand for Irrigation with the average Highest monthly Water Demand were recorded in the month of August amounting to 350.4 million $m^3$ and 56.9 million $m^3$ for Irrigation and domestic respectively, see Figure 5-8 and 5-24 for the differences.

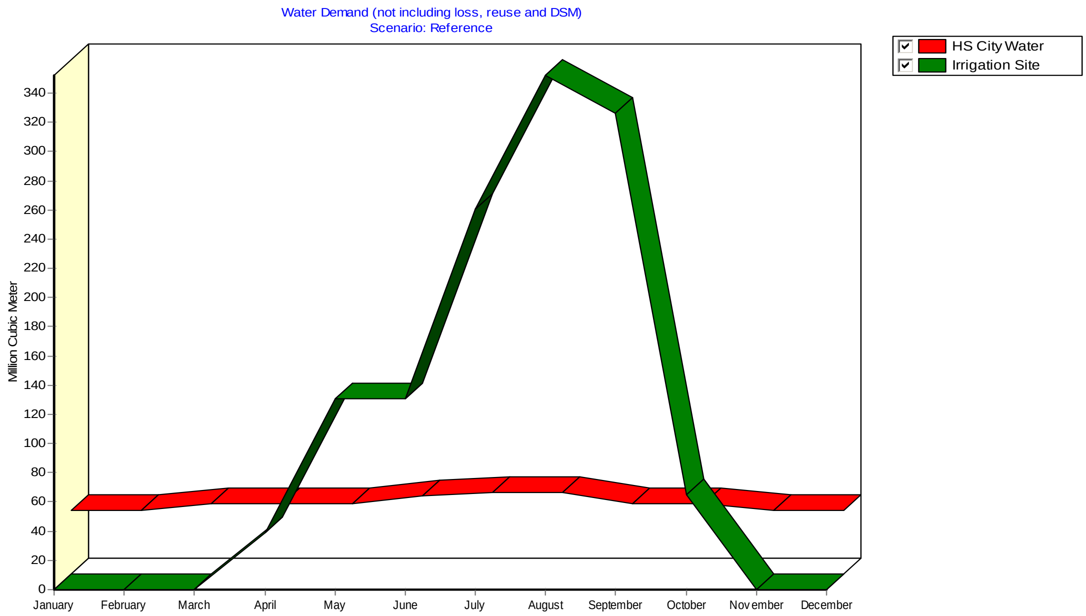



Figure 5-24: The highest water demand for both demand sites in million $m^3$ as a result of improved technology and irrigation efficiency

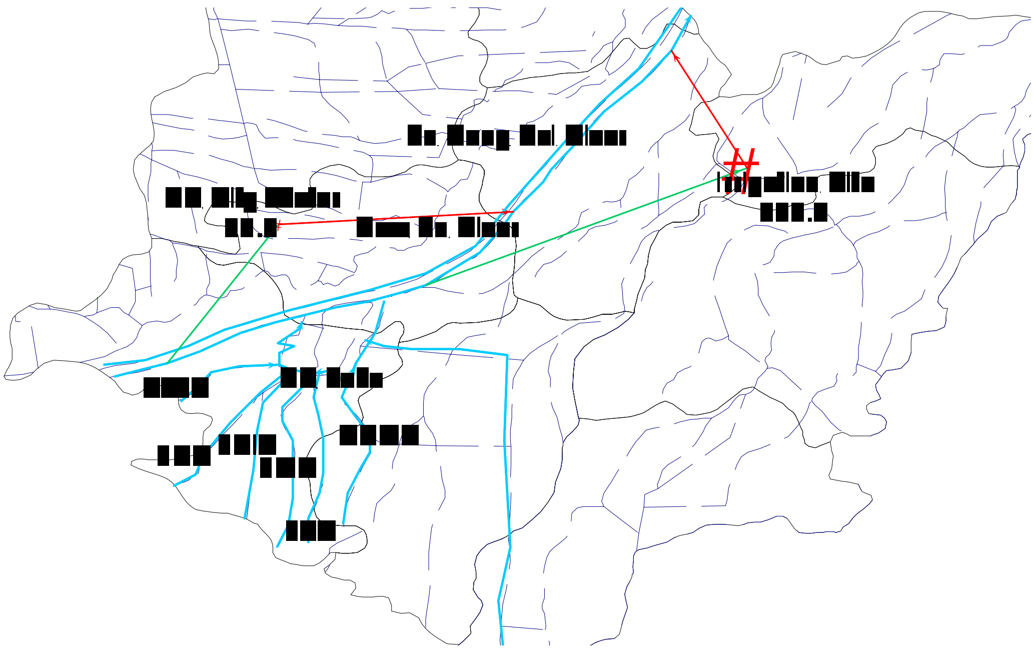


Figure 5-25: The highest monthly (August) water demand for both demand sites as a result of improved technology and irrigation efficiency.

B) With Improved Irrigation efficiency, highest unmet Water Demand reduced to

233.4 million m$^3$ as against 241.0 million m$^3$ for, Irrigation and 36.9 million m$^3$ as against 5.7 million m$^3$ for Domestic over the periods when there is no irrigation efficiency. The implication is that, for there to be water sustainable development, there is need to improved irrigation efficient technology as well as curb population for any meaning economy development to take place.

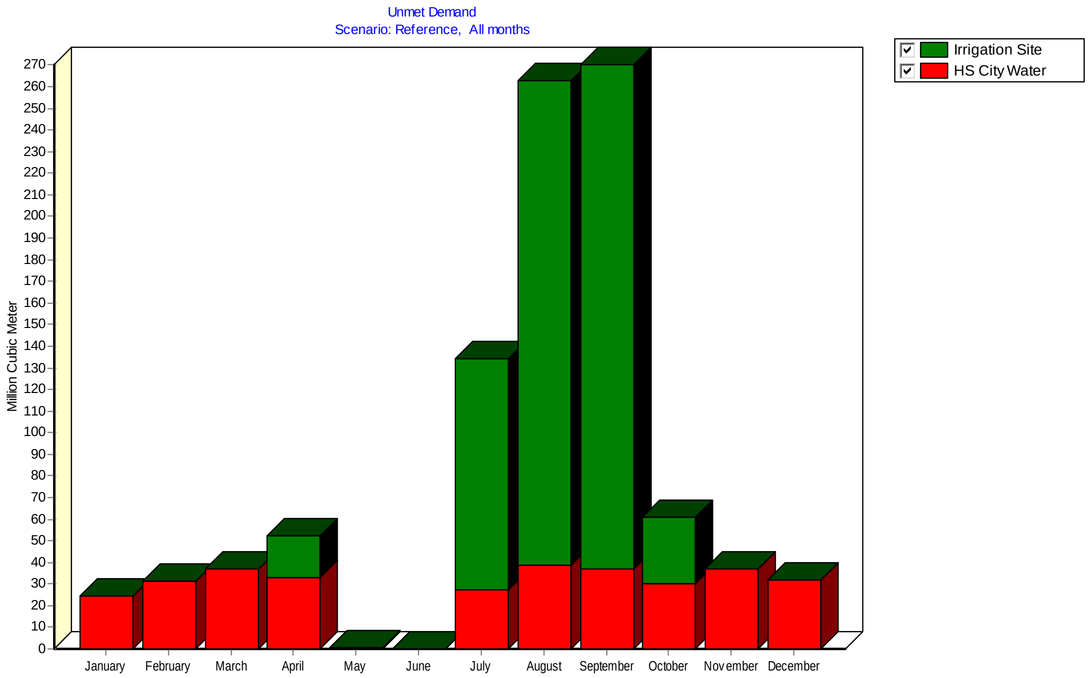



Figure 5-26: The highest unmet water demand for Irrigation and HS City as a result of improved technology and irrigation efficiency in million m$^3$

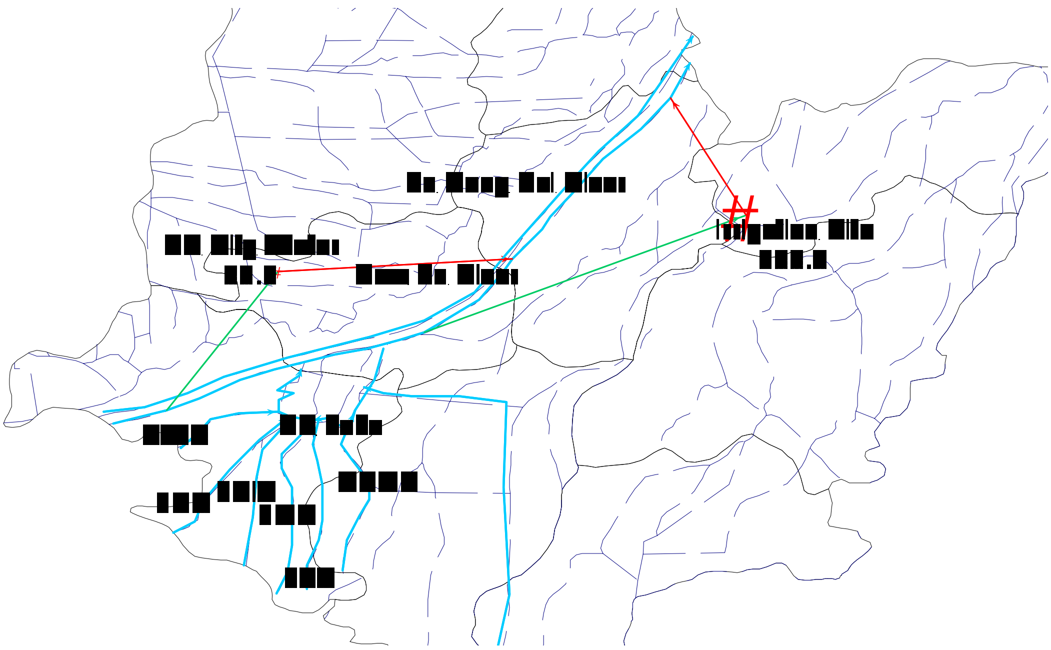


Figure 5-27: The highest monthly (September) unmet water demand for both demand sites as a result of improved technology and irrigation efficiency.

### 5.5.2 Conclusion of Demand Scenario

We can see that with population growth of 1.12 %, Irrigation growth of 1.2% and slight improved irrigation technology, comparing table 5-3 and 5-7, though the unmet water demand for irrigation also increases, this is because of the growth attributed to it in this period, given same condition of water supply availability and preference priority, what is evident, is that, there is a decrease in water demand coverage for irrigation with slight improved technology and population growth over irrigation without irrigation efficiency from 56.33% to 52.65%. On the other hand, there was increase water demand for domestic uses because of the increase population growth, so also did the unmet water demand increases, and subsequently the demand coverage substantially decreases from 80.80% to 44.83%, more water is made available for domestic water usage from irrigation because of irrigation efficiency. The effect is negligible because of the increase in population growth.

*Table 5-8: Percentage coverage for different population growth rate scenarios (In Million $m^3$)*

| | 1.12% Population Growth and SIIT | | | 2.0% Population Growth and SIIT | | |
|---|---|---|---|---|---|---|
| | Water Demand | Unmet Demand | % Coverage | Water Demand | Unmet Demand | % Coverage |
| City Uses | 22,569.9 | 12,450.8 | 44.83 | 28,680.6 | 17,097.6 | 40.39 |
| Irrigation | 49,316.8 | 23,355.2 | 52.64 | 49,316.8 | 24,004.3 | 51.33 |
| Sum | 71,886.7 | 35,806.0 | 50.19 | 77,997.4 | 41,101.9 | 47.30 |

Going by the computation on table 5-8, we can observe that, as population increases, there is bound to be high water demand, and subsequently the water demand coverage also reduce since the supply ability of the Fu Dong Pai, precipitation and Heng Shui Lake were slightly constant for the said period of modeling. With a slight increase of 0.8% growth rate, they will be reduction of about 3% water coverage even in the face of slight improved irrigation technology, because the population growth will affect the city water use that will invariably offset any meaningful reduction attributed to irrigation efficiency. We can see chart 5-28 and chart 5-29 for graphical presentations.

### 5.5.3 Scenario Analysis and Results

**-Introduction**

Scenario analysis aims to answer "What if…?" questions. Data are essential to evaluate the current and past situation, while models are indispensable in exploring options for the future.

This chapter deals with the result of the scenarios. The results were compared and linked with previous studies.

The main studies that were linked to the results are which modeled the water balance of Heng Shui Lake, from 1932- 2000. The following graphs were directly obtained from the software scenarios and were used in Excel to be compared with other studies.

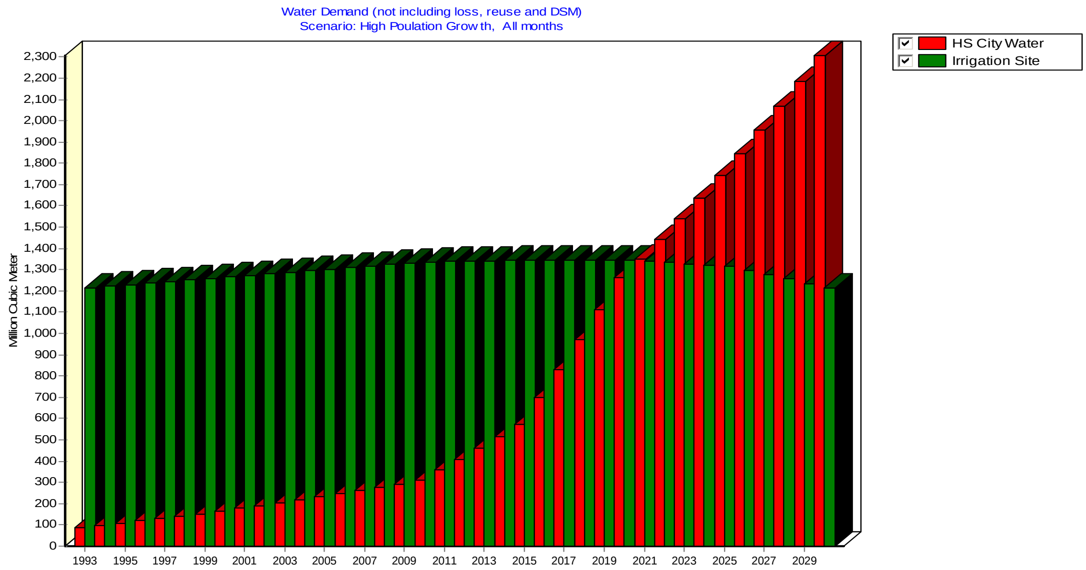



Figure 5-28: The effect of 2.0% Higher Population Growth shows annual increasing rate of water demand for HS City and the curvilinear demand rate for Irrigation.

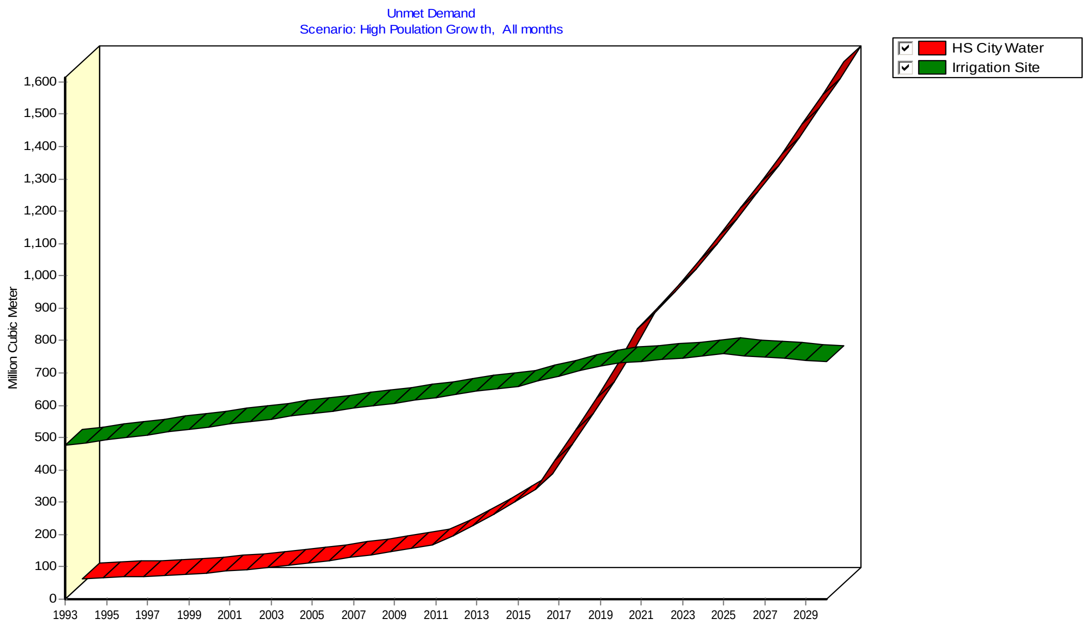



Figure 5-29: Showing the effect of 2.0% Population Growth Shows annual increasing rate of unmet water demand for both demand sites.

**-Using The Water Year Method Scenario (2006-2030)**

The Water Year Method allows using the historical data in a simplified form and to easily explore the effects of future changes in hydrological patterns, which can be a useful tool to test a hypothetical event. In this Scenario the data that was prepared in chapter 3 will be used in the Water Year Method. It is very important to study this scenario because it helps to understand and to explore in simple way the sensitivity to climate change.

These fractions are derived from historical flows by statistical analysis. The years are

first grouped into five sets (quantiles), and then their variation from the norm is computed to reach this coefficient. The years simply had to be sorted from lowest to highest for 1932-2000 for the average annual inflow.
Finally the coefficient was computed as the average divided by the normal water year average. The most important parameter in the water Year Method is the coefficient for the water year definition. Which include 0.7, 0.8, 1, 1.3, and 1.45 for very dry, dry, normal, wet and very wet respectively, the water year definition specifies how much more or less water flows into the system in that year relative to a normal water year.

Table 5-9: The Water Year Method statistical input

| Method | Very Dry | Dry | Normal | Wet | Very Wet |
|---|---|---|---|---|---|
| Year | 2008,2016. | 1996-1997, 2009, 2010,2015, 2019-2020, 2022, 2027, 2029 | 1993-1995, 2000-2007 , 2012,2014, 2017-2018, 2023, 2025, 2028 | 2011,2013,2021 2028-2029, 2026, 2030 | 1998-1999 2026, 2030, 2024 |

The chart below show some level of water hydrology variation due to climatic change affecting the trend of water variation, note that the amount of water resource demand difference will be insignificant in the short run as the variation tends to compensate for the losses from year to year, but in the long run the effect tend to be visible as shown in Figure 5-30

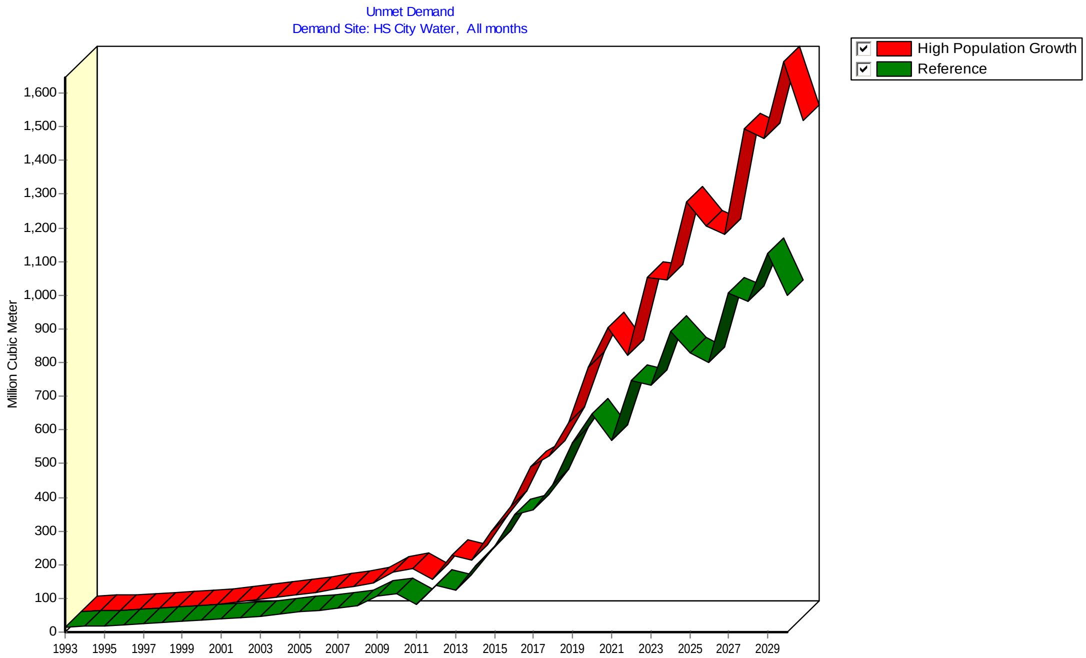



Figure 5-30: The effect of using the water year method, as it affects HS City Annual unmet demand, for the period 1993-2003

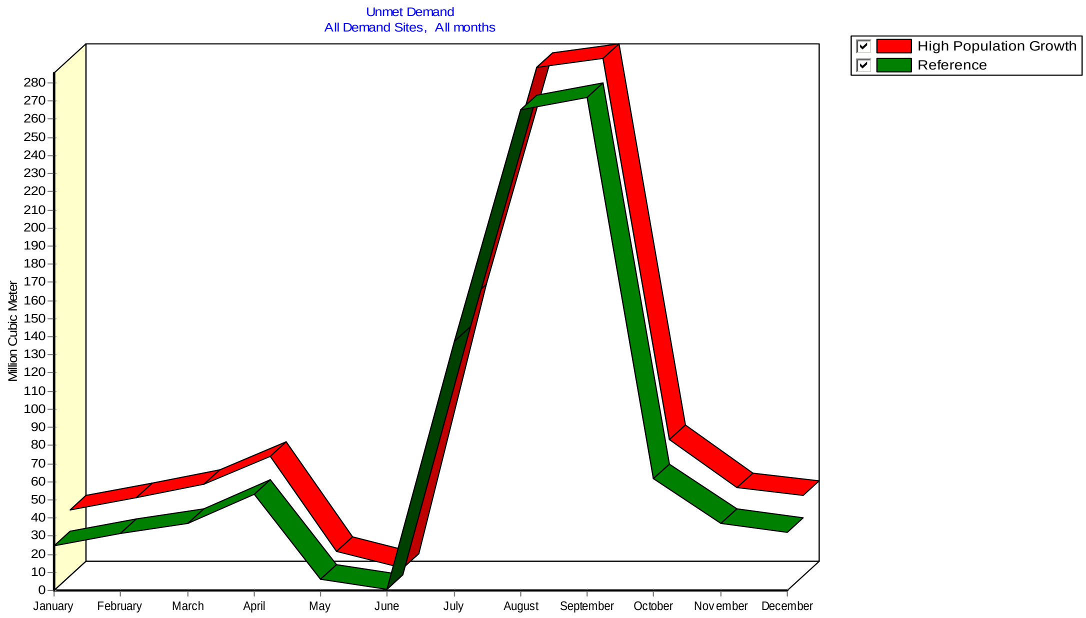



Figure 5-31: The effect of using the water year method, as it affects all demand sites monthly-unmet demand.

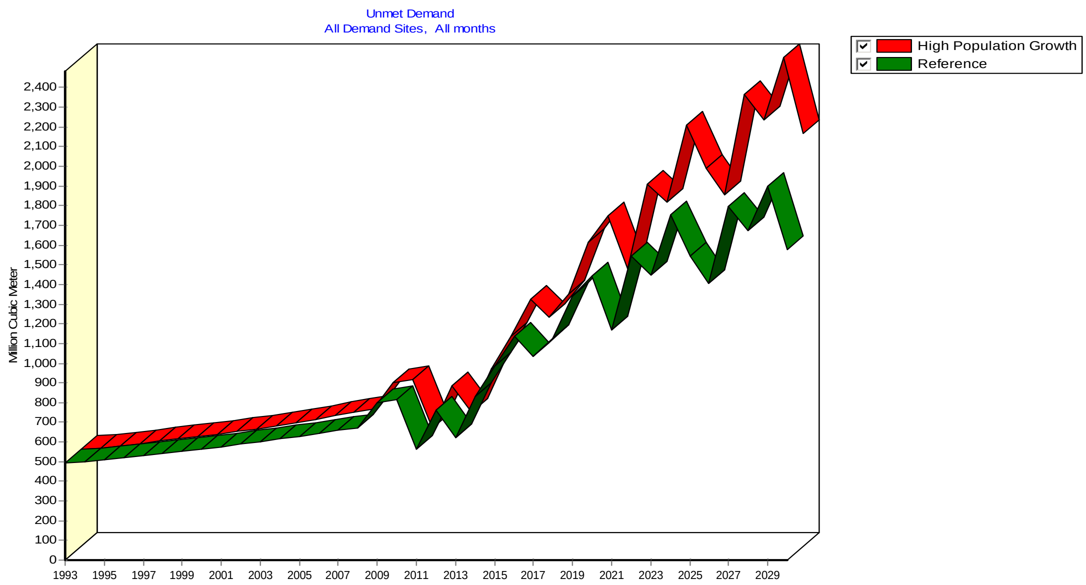



Figure 5-32: The effect of using the water year method, affecting all demand sites monthly-unmet demand.

## -Using Disaggregating Demand

Table 5-10: Annual and Total Disaggregating Demand in million $m^3$

| Uses | Annually | Total (1993-2003) |
|---|---|---|
| HS City Water | 593.9 | 22,569.9 |
| Irrigation Site | 1,297.8 | 49,316.8 |
| Rural Usage\Others | 15.7 | 598.5 |
| Rural Usage\Single Family Usage | 94.5 | 591.0 |
| Sum | 2,002.0 | 76,076.2 |

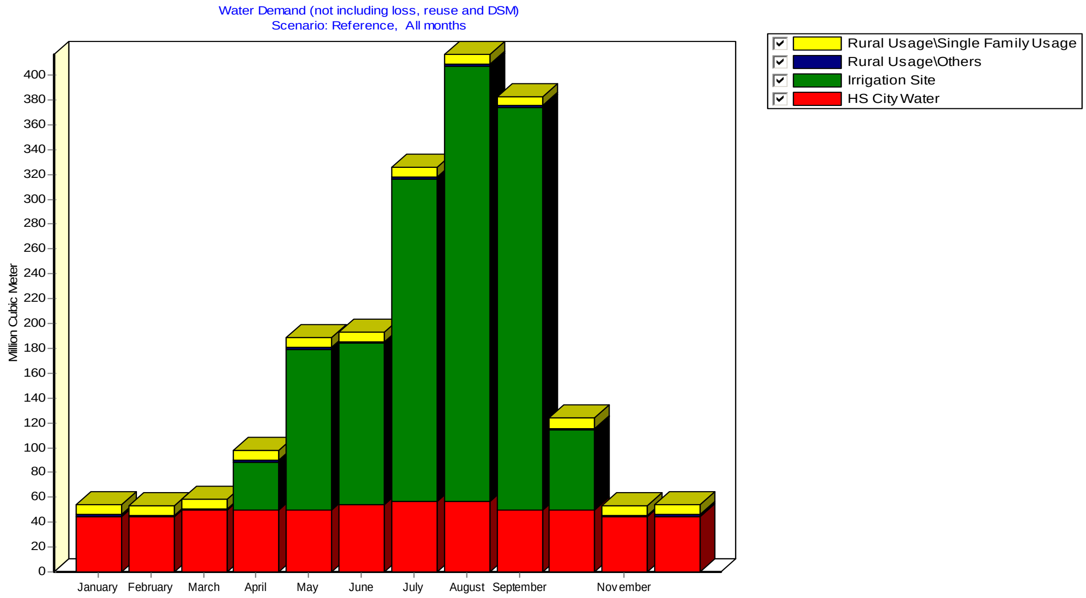



Figure 5-33: Annual Disaggregating Water Demand in million m$^3$

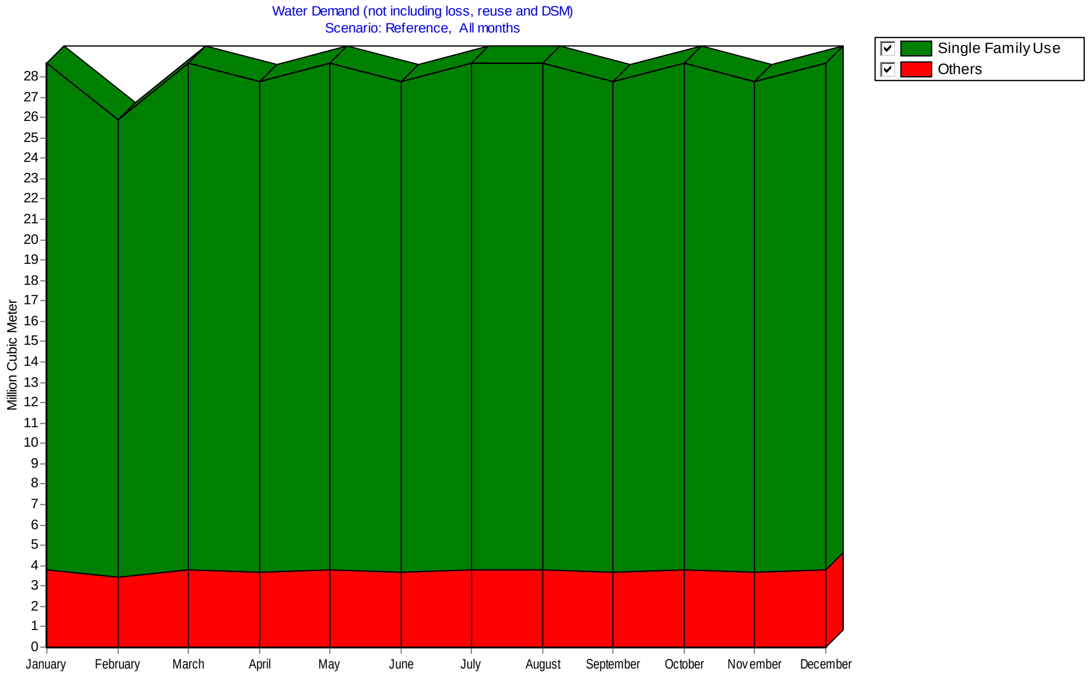



Figure 5-34: Annual Disaggregating Rural Water Demand for Single Family, in million m$^3$

The Variation in the rural demand varies along the year even though we have not entered any variation, due to the fact that WEAP assumes a constant daily demand per day. (No monthly demand was specified by the user), so months that have less days (like February) have a lower demand than months that have more days (like January)

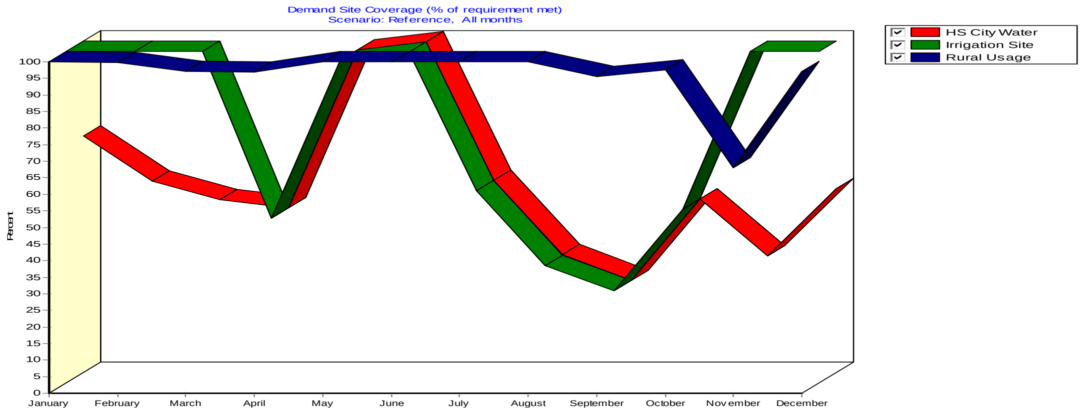



Figure 5-35: Annual Percentage Disaggregating Water Demand coverage.

The Rural coverage is almost 100% even though they have same water demand priority level, because, its withdrawal point is downstream of the return flow point for the HS City and Irrigation site, which means there is an additional volume of water available in the river; this return flow can easily cover the rather small Rural demand.

Note that in the "Reference" scenario, for the spring and the late summer, both HS City and Irrigation do not get full coverage of their demand because they both compete equally for the Main Fu Dong Pai River flow. When HS City is given preference for meeting demand (Changing Demand Priorities scenario), However, its coverage improves relative to Irrigation. Sometimes, coverage could be 100% for Irrigation, but not for HS City- that is because there is no Irrigation demand (primarily observed for the winter months).

**-Model Reuse**

Another water conservation strategy that could be studied with scenario is water reuse, which apply the formulae below for it computation.
Reuse Rate accounts for water recycling or reuse. This adjustment refers to processes by which water is used in more than one application before discharge. For example, irrigation water may be routed for reuse in more than one field. In industry, water may be recycled for multiple uses. The effect of reuse is to reduce the supply requirement by the factor (1 - reuse rate).

**Using the smooth curve formulae $Y = a + b. X + c. X^2 + d. X^3 + e. X^4 +$**

When we compare the Unmet Demand for HS City before (Reference) and after (HS City Reuse), instituting this conservation strategy. We get figure 5-36 showing substantial reductions in HS City Unmet Demand when the water reuse strategy is used.

Table 5-11: The Water Reuse Strategy for the period in million m3 (1993-2030)

| | Water Reuse without water losses | Water Reuse with 20% water losses |
|---|---|---|
| HS City Water Reuse | 7,515.8 | 10,057.5 |
| Reference | 12,710.8 | 16,858.7 |

| | | |
|---|---|---|
| unmet demand | 40.13% | 40.34% |

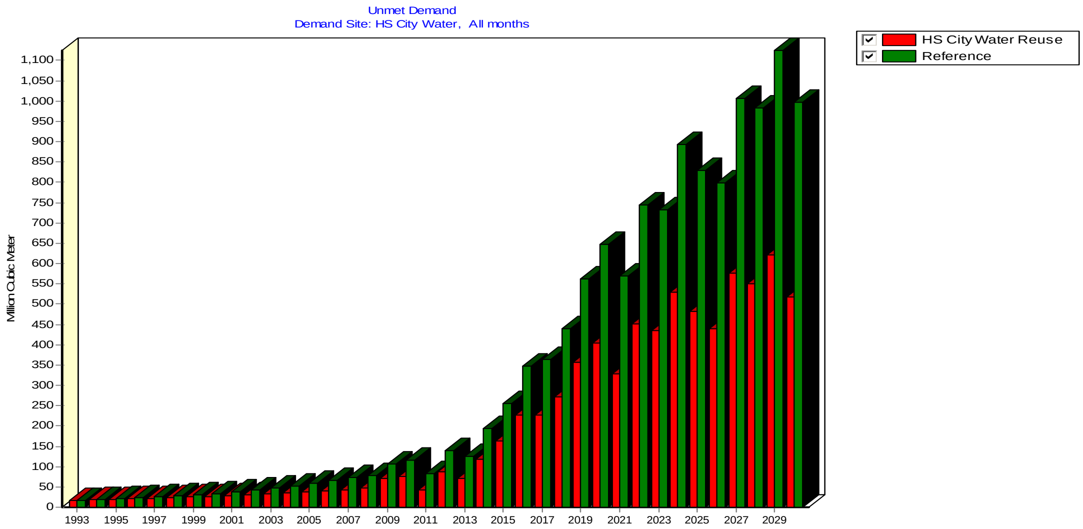



Figure 5-36: The effect of water reuse strategy showing substantial reductions in HS City Unmet Demand.

**-Model Losses**

Loss Rate accounts for any distribution losses within each demand site. For example, in municipal systems, distribution losses could represent physical leaks, unmetered water use in public parks and buildings, clandestine connections, or water used for line flushing. The effect of distribution losses is to increase the supply requirement by the factor (1 + loss rate). This does not include losses that are already accounted for as transmission link losses.

Re- editing the model to take into account the fact that there is a 20% loss rate in the network of HS City, this change is made in the current account so that it is carried along the Reference scenario, and as a result is inherited in all the scenarios.

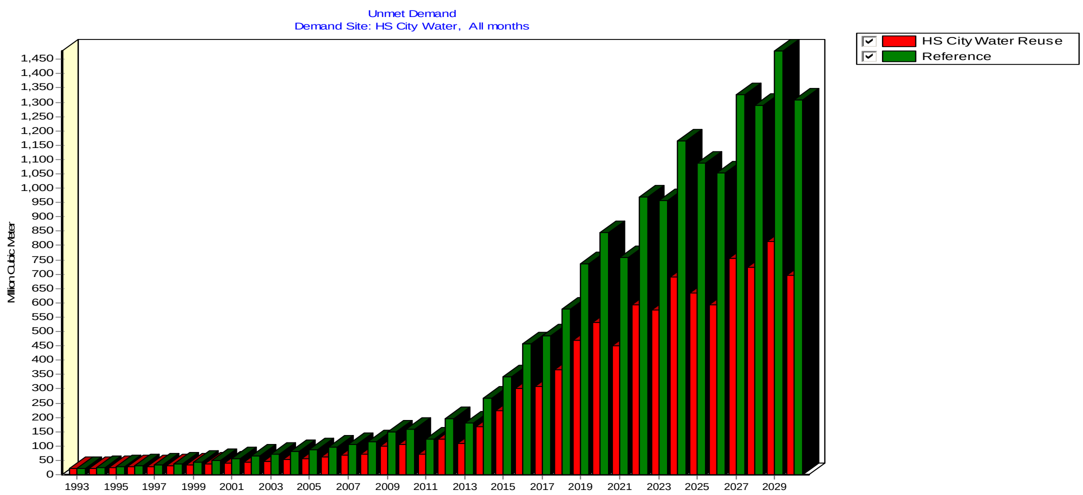



Figure 5-37: Computation of 20% water losses Shows slight reductions for HS City Unmet Demand

What happens to the unmet demand for the HS City, both in the “Reference “scenario

compared to the earlier computation without losses?
Losses can happen in Transmission Link, in the Demand Site itself or in the Return flow. Losses in the Transmission Link will affect the supply to the Demand Site. Losses in the Demand Site will affect the required supply Requirements of this Demand Site. Losses in the Return Flow will only affect the flow returned

## 5.6 Refining The Supply

The supply variable will be considered from four aspects namely; Changing supply priorities, Modeling Reservoirs, Adding Flow Requirements, and Modeling Groundwater Resources.

Table 5-12: The variable for Water Supply entities in HS City (1993-2030)

| RESERVOIR | Set up year | Capacity | Flow Requirement | Priority |
|---|---|---|---|---|
| | 1995 | 246,500,000 $m^3$ | 7.2 CMS | 99 |
| GROUNDWATER | Set up year | Storage Capacity | Initial Capacity | Natural Recharge |
| | 1995 | Unlimited | 296,000,000 $m^3$ | Mar-Oct 50,000,000 $m^3$ |

### Changing supply priorities

The conceptual model of reuse of urban wastewater for irrigation purposes is linking the HS city water use to the Irrigation demand site, using the transmission link.

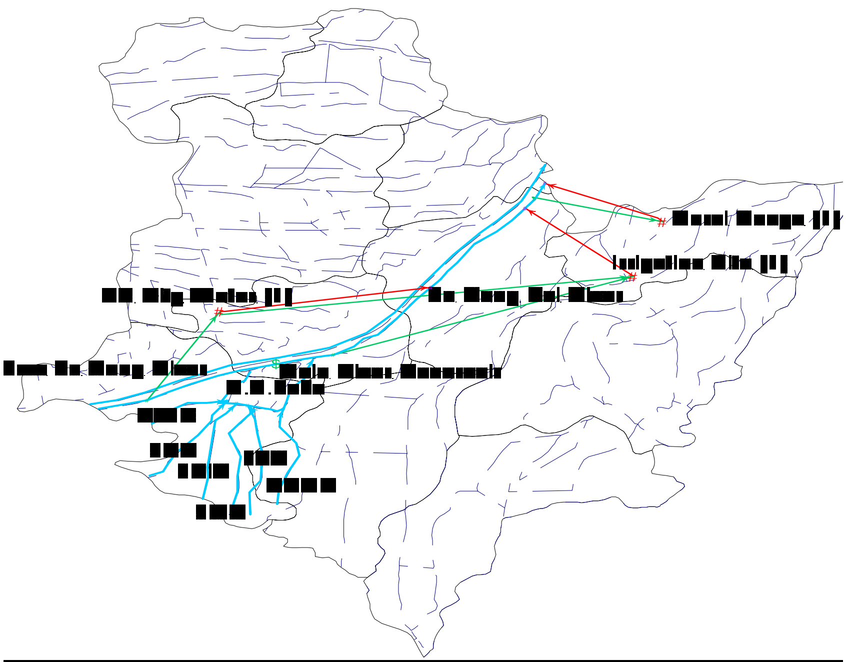


Figure 5-38: The reservoir added to the model.

If water quality were a concern, a wastewater treatment plant could have been added to treat the water from the HS City before Irrigation received it. Having the treatment plant in the schematic would it possible to simulate the changes in the water quality and after treatment

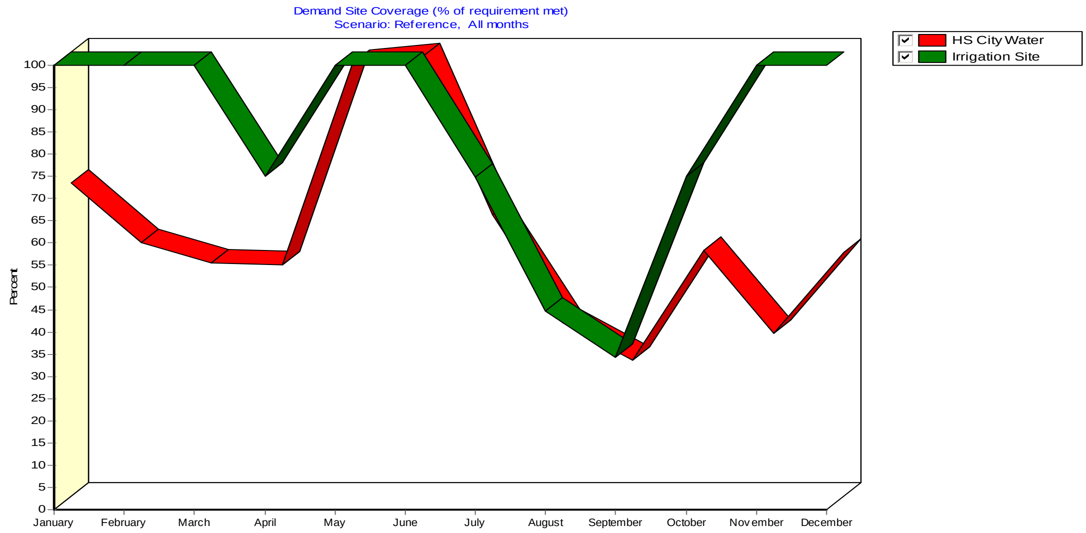



Figure 5-39a: The effect of changing water supply priority to all demand nodes. Supply Preference, 1 from the River, 2 from HS City

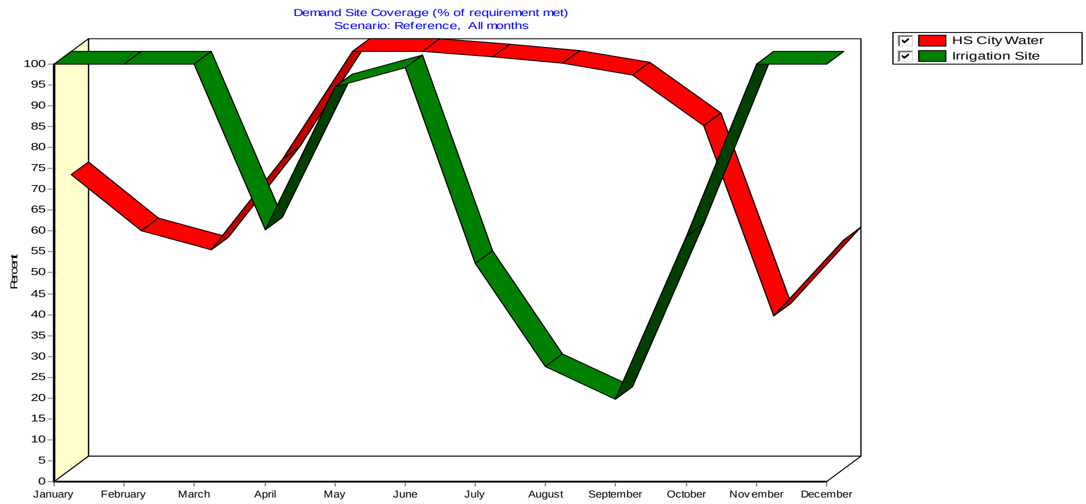



Figure 5-39b: The effect of changing water supply priority to all demand nodes. Supply Preference,2 from the River, 1 from HS City

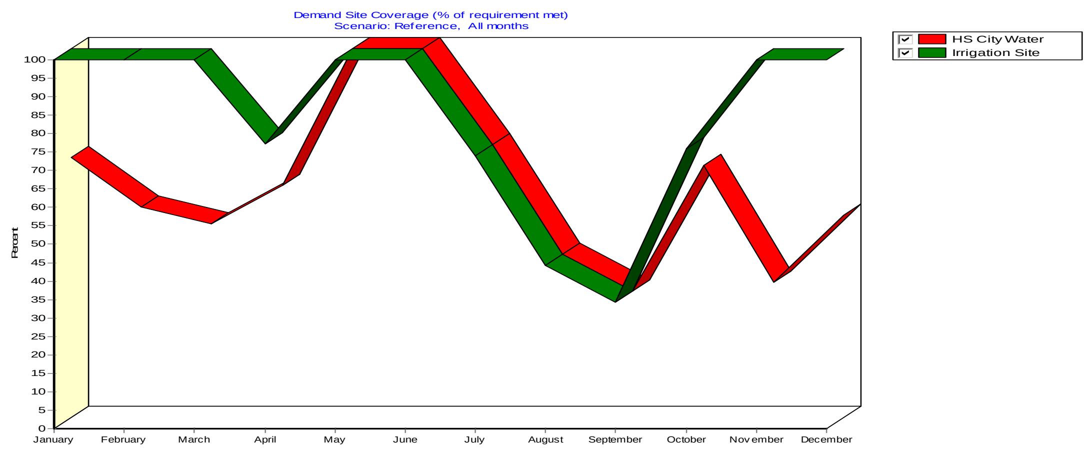



Figure 5-39c: The effect of changing water supply priority to all demand nodes.

Supply Preference, 1 from the River, 1 from HS City

### 5.6.1 Modeling Reservoir

**River Reservoir Flows**

A reservoir's (*Res*) storage in the first month (*m*) of the simulation is specified as data below

$$\textit{Begin Month Storage}_{Res,m} = \textit{Initial Storage}_{Res} \text{ for m = 1} \qquad \text{5-7}$$

Thereafter, it begins each month with the storage from the end of the previous month.

$$\textit{Begin Month Storage}_{Res,m} = \textit{End Month Storage}_{Res,m-1} \text{ for m > 1} \qquad \text{5-8}$$

This beginning storage level is adjusted for evaporation. Since the evaporation rate is specified as a change in elevation Supply and Resources, the storage level must be converted from a volume to an elevation. This is done using the volume-elevation curve

Thus, evaporation is calculated as a fraction of upstream inflow to the reach.

$$\text{Evaporation}_{Rch} = \text{Evaporation Fraction}_{Rch} \text{ x Upstream Inflow}_{Rch} \qquad \textit{5-9}$$

$$\textit{Begin Month Elevation}_{Res} = \textit{Volume To Elevation (BeginMonthStorageRes)} \qquad \textit{5-10}$$

The elevation is reduced by the evaporation rate.

$$\textit{Adjusted Begin Month Elevation}_{Res} = \textit{Begin Month Elevation}_{Res} - \textit{EvaporationRate}_{Res.}$$

Then the adjusted elevation is converted back to a volume.

$$\textit{Adjusted Begin Month Storage}_{Res} = \textit{Elevation To Volume (Adjusted Begin Month Elevation}_{Res}\textit{)} \qquad \textit{5-12}$$

While the reservoir’s operating rules determine how much water is available in a given month for release, it is given by equation below.

$$\textit{Storage For Operation}_{Res} = \textit{Adjusted Begin Month Storage}_{Res} + \textit{Upstream Inflow}_{Res} + \sum_{DS} \textit{DS Return Flow}_{DS,Res} + \sum_{TP} \textit{TP Return Flow}_{TP,Res} \qquad \textit{5-13}$$

The Buffer zone coefficient is entered for the amount available to be released from the reservoir is the full amount in the conservation and flood control zones and a fraction. See equation below. Each of these zones is given in terms of volume (i.e. not elevation). The water in the inactive zone is not available for release. See Figure 5-56

$$\textit{Storage Available For Release}_{Res} = \textit{Flood Control And Conservation Zone Storage}_{Res} + \textit{Buffer Coefficient}_{Res} \times \textit{Buffer Zone Storage}_{Res} \quad \text{5-14}$$

All of the water in the flood control and conservation zones is available for release, and equals the amount above Top Of Buffer. For available water conservation see equation below.

$$\textit{Flood Control And Conservation Zone Storage}_{Res} = \textit{Storage For Operation}_{Res} - \textit{Top Of Buffer}_{Res} \quad \text{5-15}$$

Or zero if the level is below Top Of Buffer.

$$\textit{Flood Control And Conservation Zone Storage}_{Res} = 0 \quad \text{5-16}$$

Buffer zone storage equals the total volume of the buffer zone if the level is above Top Of Buffer,

$$\textit{Buffer Zone Storage}_{Res} = \textit{Top Of Buffer Zone}_{Res} - \textit{Top Of Inactive Zone}_{Res} \quad \text{5-17}$$

Or the amount above Top Of Inactive if the level is below Top of Buffer,

$$\textit{Buffer Zone Storage}_{Res} = \textit{Storage For Operation}_{Res} - \textit{Top Of Inactive Zone}_{Res} \quad \text{5-18}$$

Or zero if the level is below Top Of Inactive.

$$\textit{Buffer Zone Storage}_{Res} = 0 \quad \text{5-19}$$

WEAP will release only as much of the storage available for release as is needed to satisfy demand and instream flow requirements, in the context of releases from other reservoirs and withdrawals from rivers and other sources. (As much as possible, the releases from multiple reservoirs are adjusted so that each will have the same fraction of their conservation zone filled. For example, the conservation zone in a downstream reservoir will not be drained while an upstream reservoir remains full. Instead, each reservoir's conservation zone would be drained halfway.)

$$\textit{Outflow}_{Res} = \textit{Downstream Outflow}_{Res} + \sum_{DS} \textit{TransLink Inflow}_{Res,DS} \quad \text{6-20}$$

Where $\textit{Outflow}_{Res} \leq \textit{StorageAvailableForRelease}_{Res}$

The storage at the end of the month is the storage for operation minus the outflow.

$$\textit{End Month Storage}_{Res} = \textit{Storage For Operation}_{Res} - \textit{Outflow}_{Res} \quad \text{6-21}$$

The change in storage is the difference between the storage at the beginning and the end of the month. This is an increase if the ending storage is larger than the beginning, a decrease if the reverse is true.

$$Increase\ In\ Storage_{Res} = End\ Month\ Storage_{Res} - Begin\ Month\ Storage_{Res} \qquad 5\text{-}22$$

Simulating reservoir model, we can compare the Demand Site Coverage for Irrigation in the "Reference" and "Reservoir Added" scenarios. See the graphical representation.

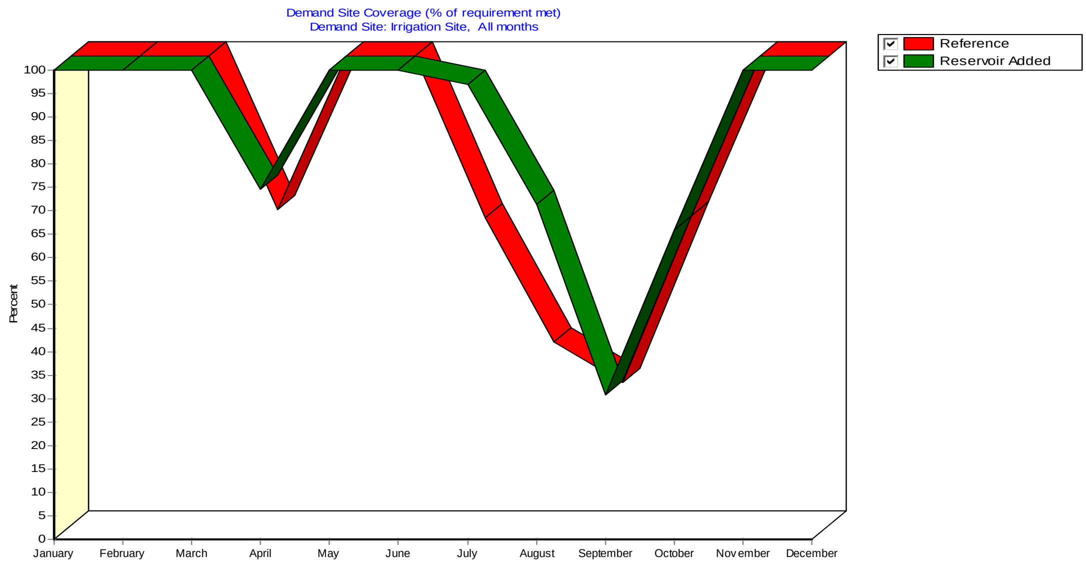



Figure 5-40a: Percentage coverage of Reservoir Added scenarios on Irrigation water usage.

Although a total capacity of 246,500,000 $m^3$ of Heng Shui lake was initial added to the supplement water resource to Heng Shui Municipality, the resultant effect appear not sustainable, and the effect of its supply is very insignificant as shown on chart 5-40a, 5-40b to Figure 5-41, suggesting that, for a meaningful sustainable development, the reservoir must be supplement or its capacity increased, better still water importation could be a best alternative.

The reason Irrigation have a better coverage over HS City water use is due to the fact that, at some time in the year especially, during the winter and the spring months, the water demand for irrigation is virtually zero while the city is not, and the water supply preference priority for all demand node is the same, see Figure 5-41

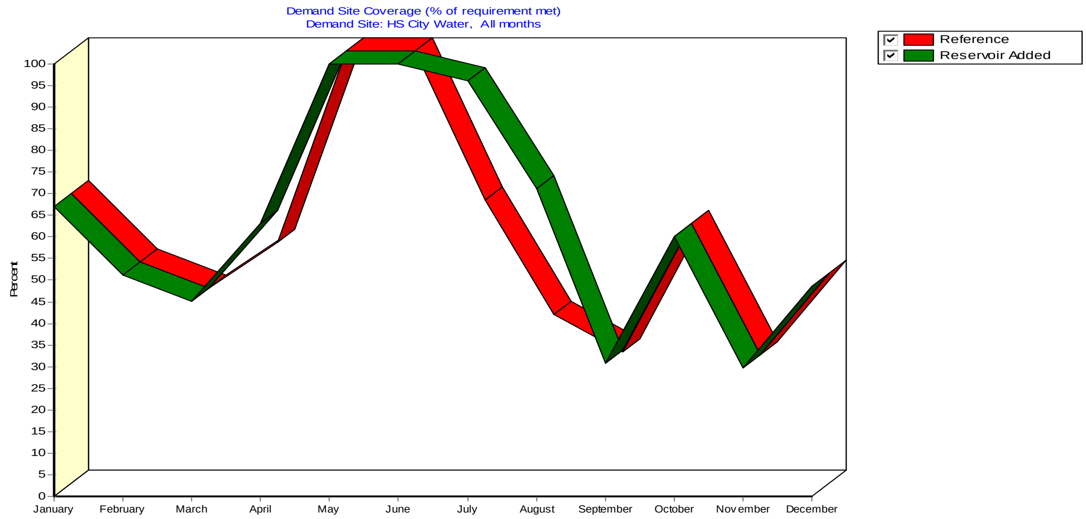



Figure 5-40b: The Percentage coverage of Reservoir Added scenarios on HS City water usage.

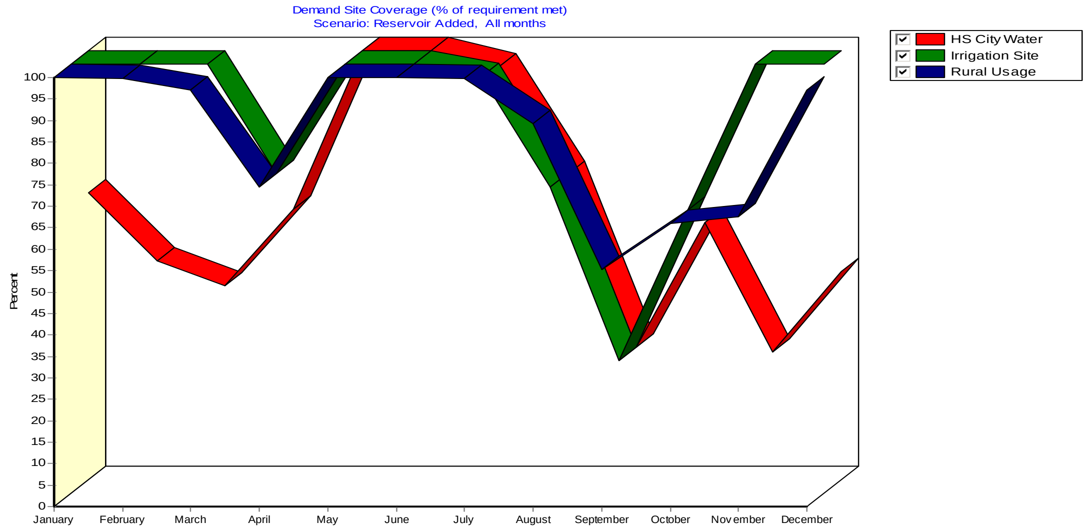



Figure 5-41: The percentage coverage of Reservoir Added scenarios on Disaggregate water usage.

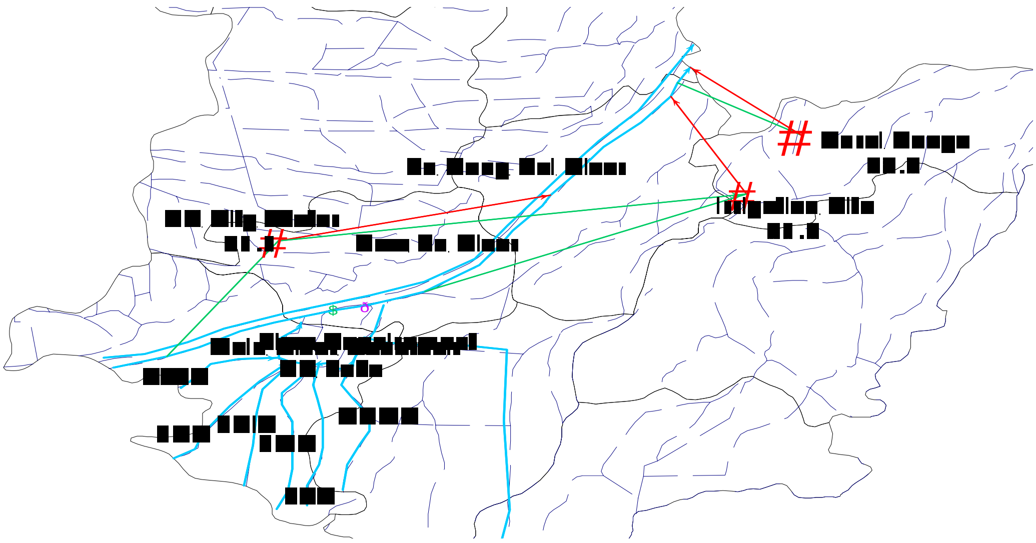


Figure 5-42: Highest monthly (August) percentage demand site coverage of Reservoir Added.

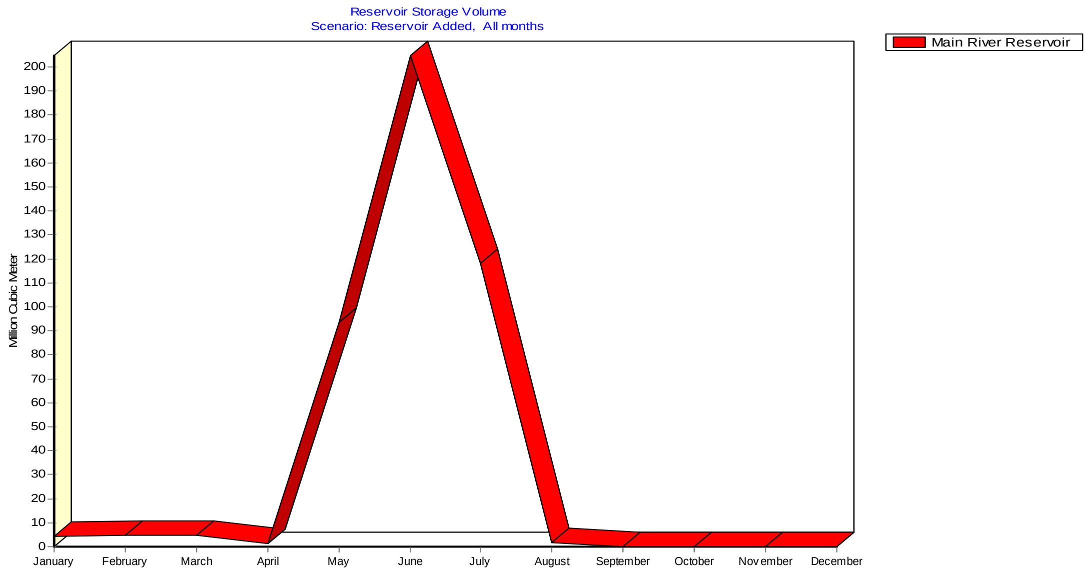



Figure 5-43: The amount of monthly Reservoir Storage Volume distribution.

The level of reservoir storage volume get to it peak during the month of June, because this is the period when the surface and precipitation runoff is at it peak and evaporation is also less. While figure 5-44 depicts the annual reservoir storage with some variability, the year 2010, 2016, 2020, 2024 and 2029 having low yield to reservoir capacity storage is due to the climatic and seasonal variation attributed to water year method computation.

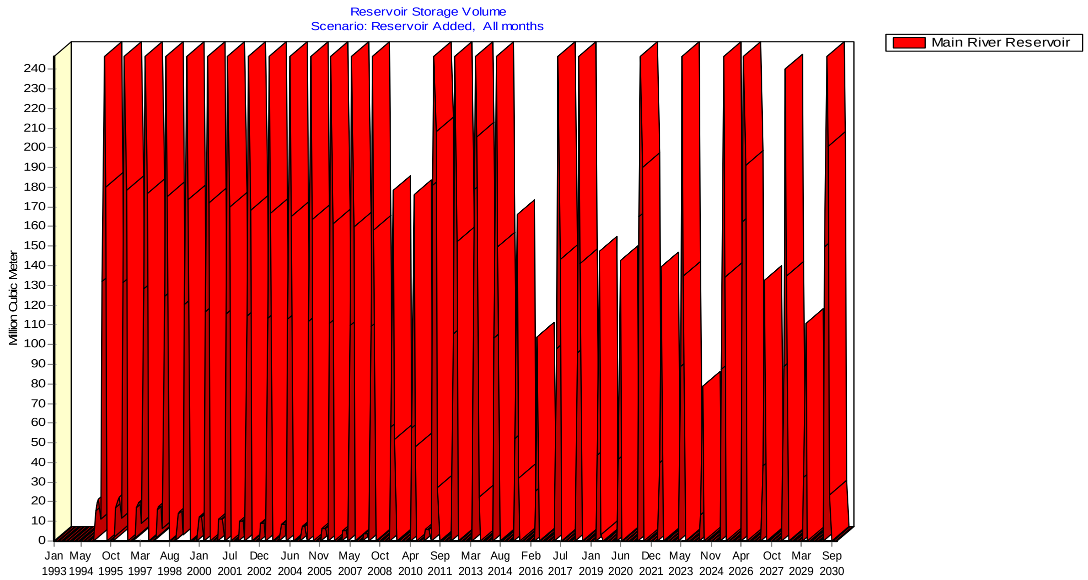



Figure 5-44: The amount of Annual Reservoir Storage Volume distribution.

From the Figure 5-45 below, the addition of reservoir alter the course and streamflow of the River flow especially all nodes after the reservoir nodes, because water have to diverted into the lake and after full storage, it continue to flow along the course of the river.

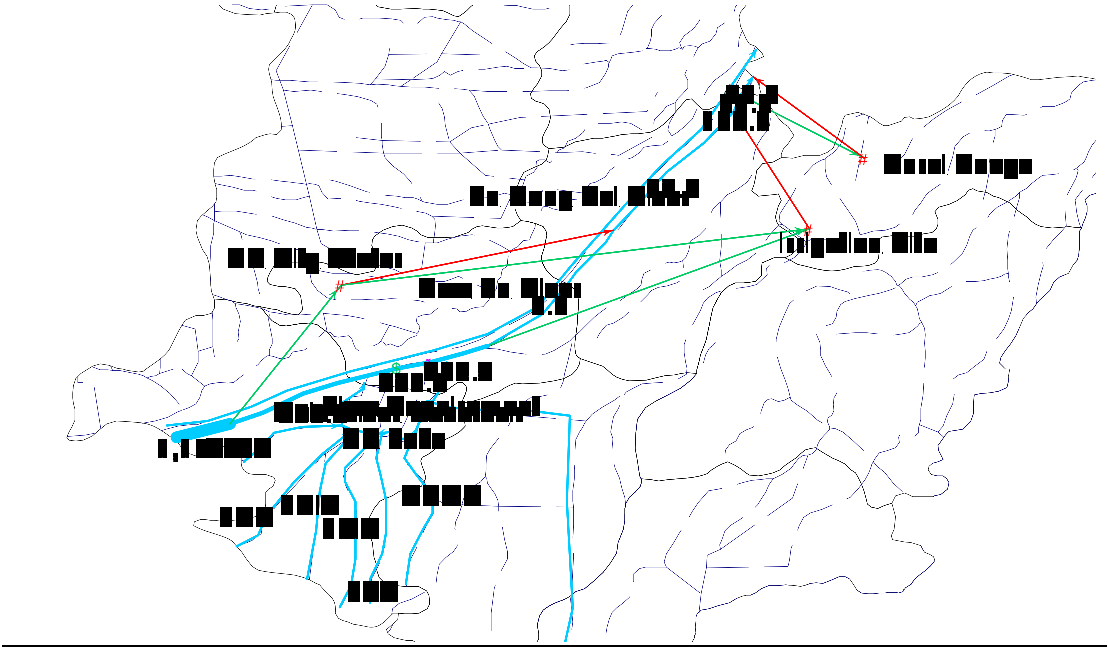


Figure 5-45: The Total Annual Streamflow when reservoir is added

**Conclusion:** The creation of a large reservoir allows storage of "excess" water during high flow periods to cover water demand during the low flow periods. The price to pay is, however, a potentially large impact on the hydrological regime of the river downstream of the reservoir. The Return Flows from HS City and Irrigation provide the flow in the Fu Dong Pai River during the spring and the winter months. A reservoir's operation variables and the flow requirements can be used to mitigate the reservoir's downstream impact.

### 5.6.2 Adding Flow Requirement

The addition of 7.2 CMS flow requirement definitely reduce the speed of the streamflow along the main Fu Dong River and this affect the rate of water supply to all demand node see Figure 5-47, The flow requirement is important in regulating the supply quantities especially during heavy flow and when strategic water management is so desire in a particular demand node.

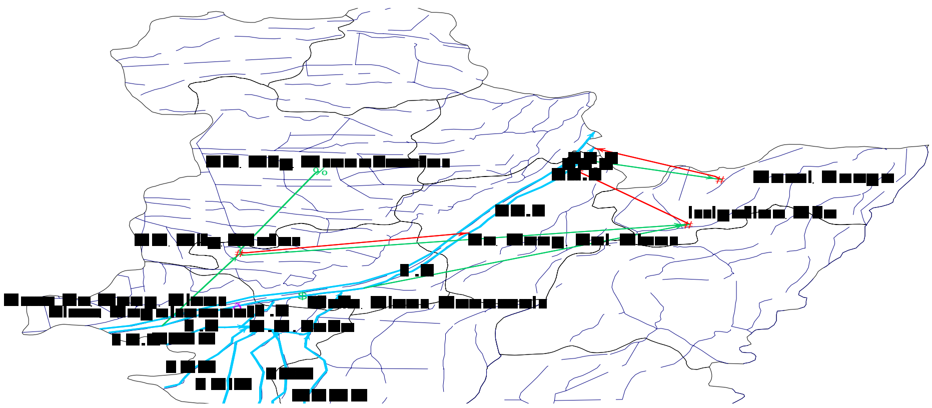


Figure 5-46: The effect of flow requirement on the streamflow

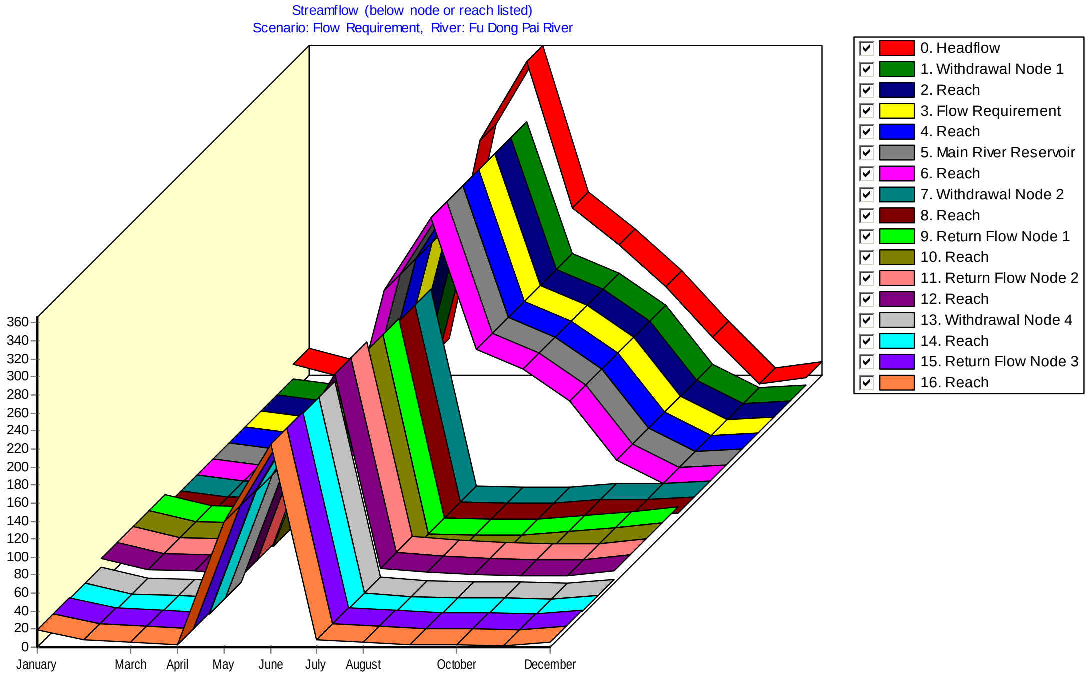



Figure 5-47: The amount of Annual water distribution as a result of defined flow requirement.

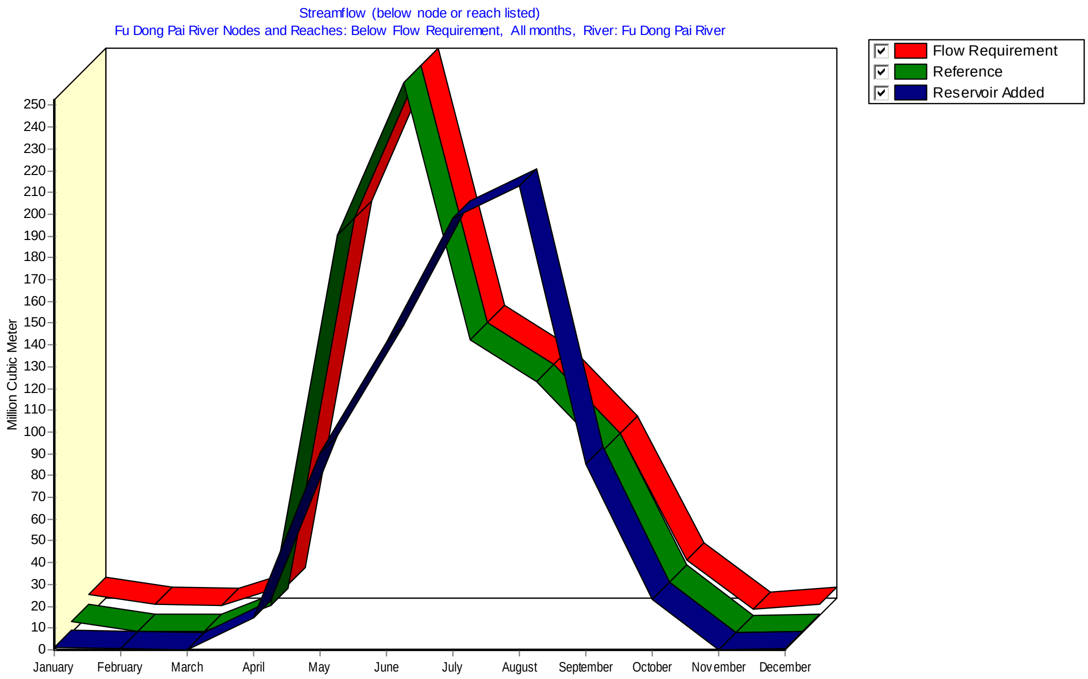



Figure 5-48: The effect of increased reservoir capacity available to irrigation site demand on monthly percentage coverage. (1993-2030)

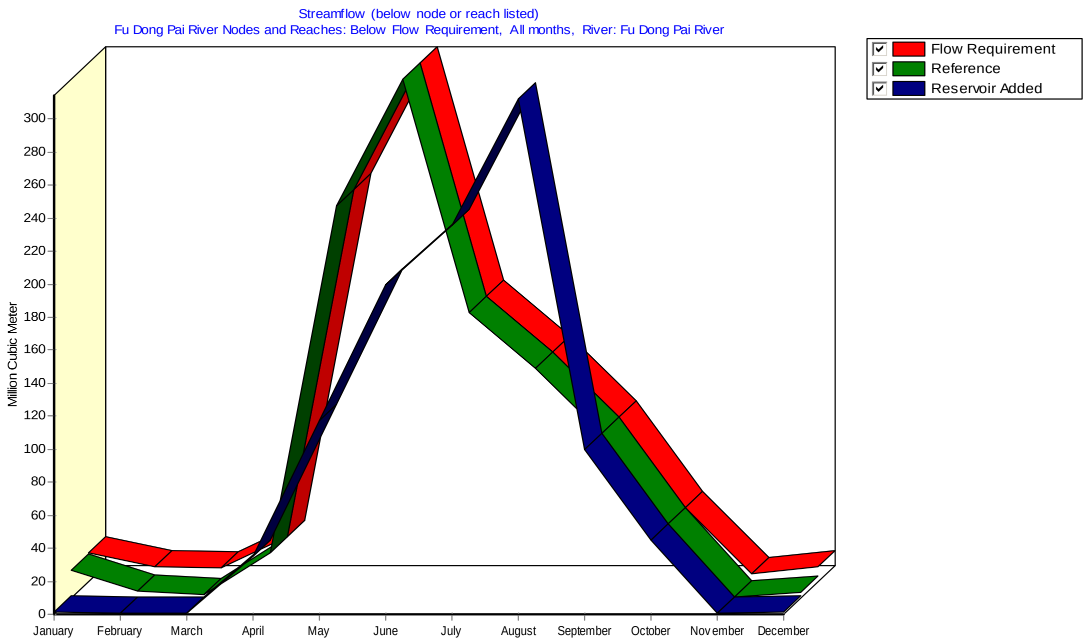



Figure 5-49: The amount of Annual streamflow quantity as a result of defined flow requirement for the year 1995

The effect of the streamflow was effective and notice in the set up year compare to the cumulative year quantities, this is because of the various effect that have interplay during the cumulative period, such as water year, drought, and heavy precipitation etc. the flow requirement seem to 100% during the Autumn and summer months because of heavy precipitation which increase the river water quantity and increase the water availability, see Figure 5-50 below.

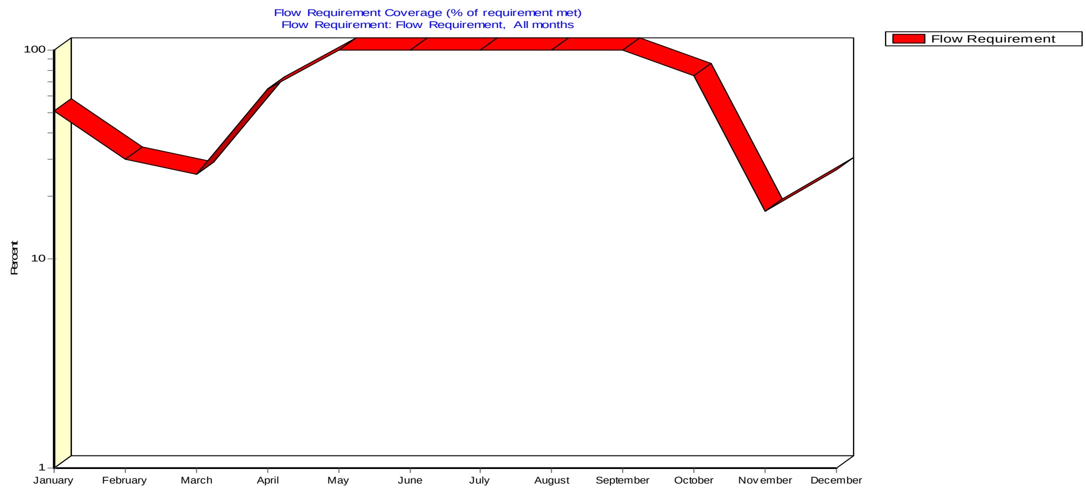



Figure 5-50: The amount of monthly percentage Coverage for flow requirement quantity

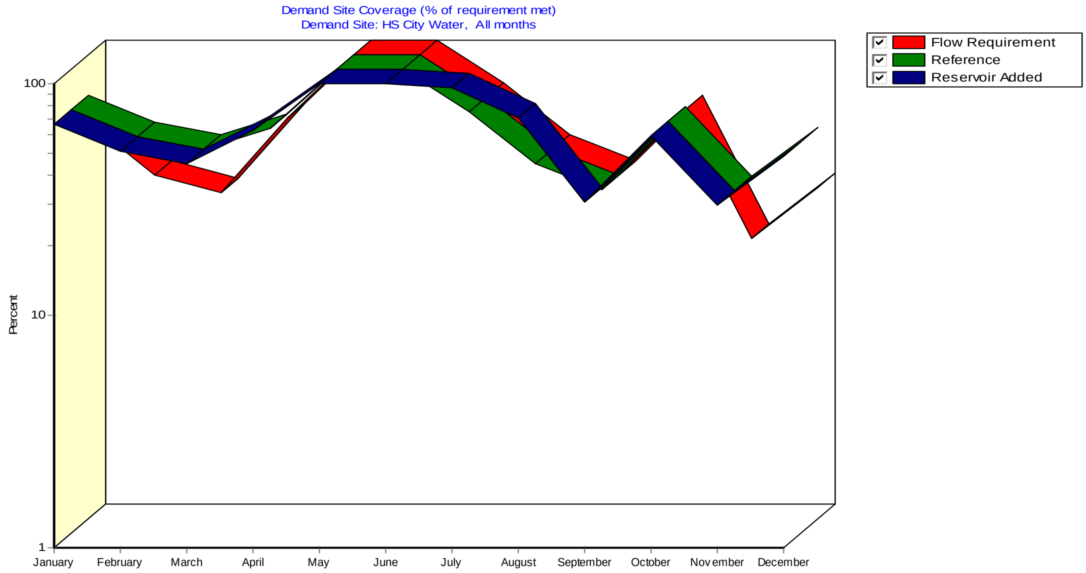



Figure 5-51: The Monthly percentage Coverage for HS City, given Flow Requirement, Reference, and Reservoir Added.

### 5.6.3 Modeling GroundWater

A groundwater node's (*GW*) storage in the first month (*m*) of the simulation is specified as data given below.

$$\text{Begin Month Storage}_{GW,m} = \text{Initial Storage}_{GW} \text{ for } m = 1 \quad \text{5-23}$$

Thereafter, it begins each month with the storage from the end of the previous month.

$$\text{Begin Month Storage}_{GW,m} = \text{End Month Storage}_{GW,m-1} \text{ for } m > 1 \quad \text{5-24}$$

The storage capacity after each month is given as.

$$\text{End Month Storage}_{GW} = \text{Begin Month Storage}_{GW} + \text{Natural Recharge}_{GW} + \sum_{Ds} \text{DSReturn Flow}_{DS,GW} + \sum_{Tp} \text{TPReturn Flow}_{TP,GW} + \text{Reach Flow To Groundwater}_{GW,Rch} - \sum_{Ds} \text{TransLink Inflow}_{GW,DS} - \text{Groundwater Flow To Reach}_{GW,Rch} \quad \text{5-25}$$

The amount withdrawn from the aquifer to satisfy demand requirements is determined in the context of all other demands and supplies in the system. The maximum withdrawals from an aquifer can be set as the equation below, to model the monthly pumping capacity of the well or other characteristics of the aquifer that could limit withdrawals.

$$\sum_{Ds} TransLink\ Inflow_{GW,DS} \geq Maximum\ Groundwater\ Withdrawal_{GW} \qquad 5\text{-}26$$

We use the Maximum flow volume or percent of demand parameter represent restrictions in the capacity (due, for example to equipment limits)

The groundwater extraction required to meet demands for HS City domestic uses, under these conditions cannot be sustainable as shown on the chart below, the groundwater storage capacity will begin to drop from the 2016 when it get to it peak supplying 6517.5 million $m^3$ of water quantities, creating water lack and hardship, if adequate preventive measures are not taken, this trend will continue until the year 2025 where the water resource extraction will be more or less zero, which is a very bad trend since the water recharge capacity cannot meet the extraction quantities, given rise to different ecological problems. Thus thereby allowing us to plan for alternative water supply using WEAP Model for the remaining period of this water resource simulation especially restriction groundwater extraction from the year 2020 upwards.

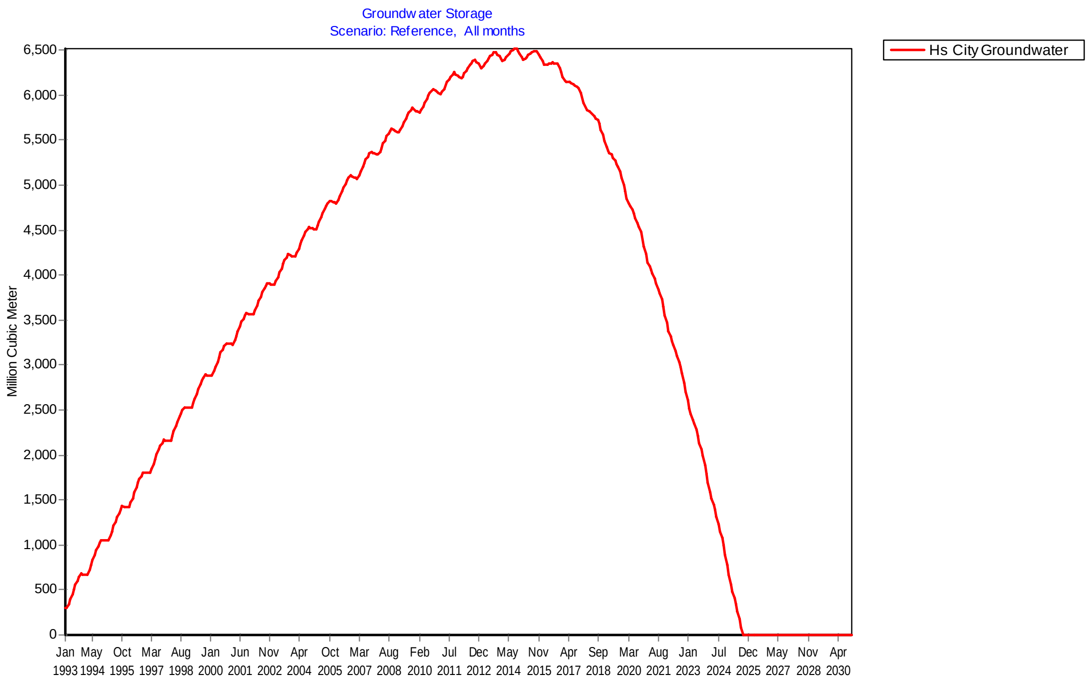



Figure 5-52: The Annual Available Groundwater Supply to all demand nodes.

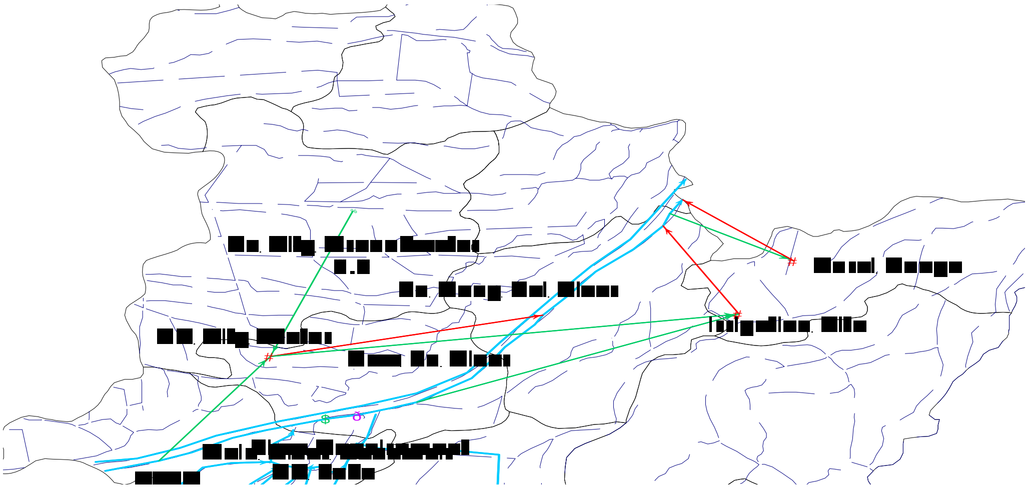


Figure 5-53: The amount of Groundwater supplyavailability for the year 2025-2030.

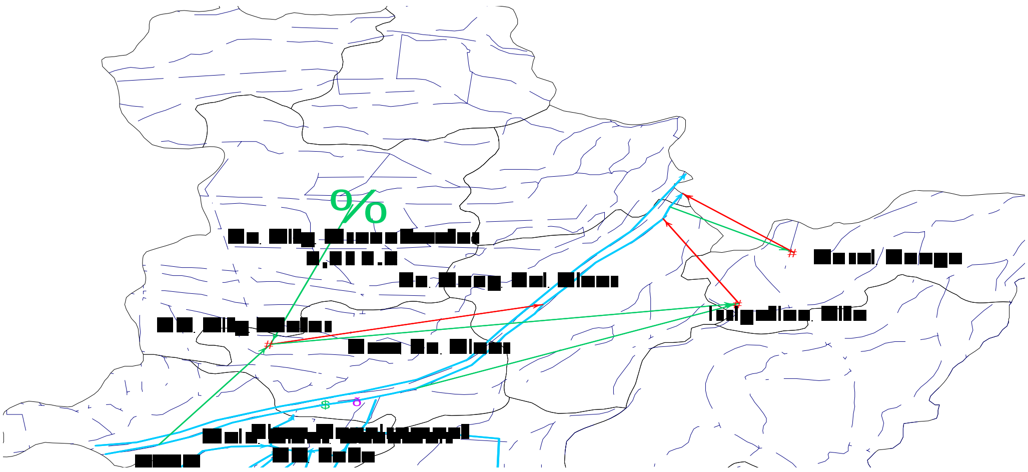


Figure 5-54: The amount of Groundwater supply availability for the year 2016.

How do the relative use of water from HS city Groundwater and the Fu Dong Pai River evolve at the HS City demand site?

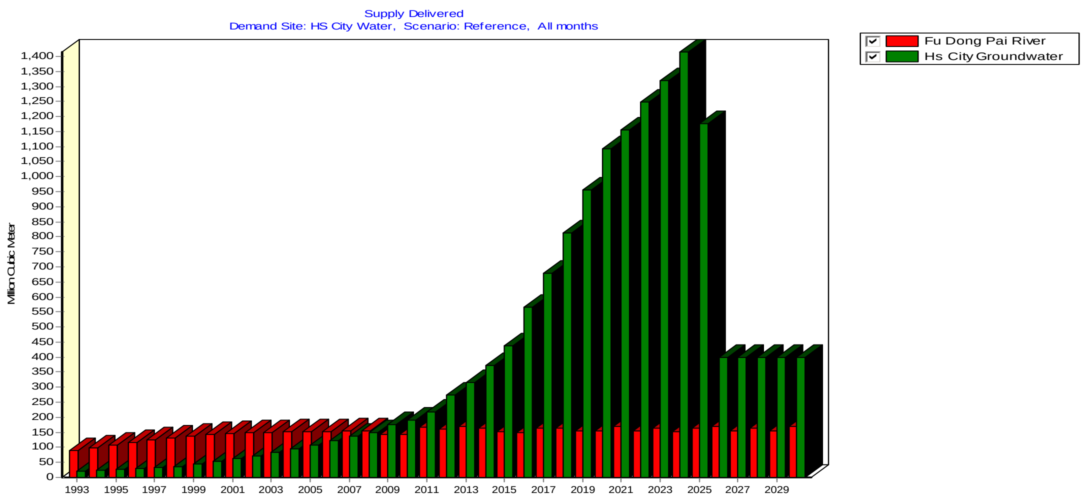



Figure 5-55: The Annual Available Groundwater + River SS to availability for HS City.

***Conclusion***

Groundwater recharge and interaction with rainfall and surface water can be modeled rather that entered as inputs. Refer to the "Hydrological Modeling" for clearer understanding. Other resources can be modeled using the "Other Supply" object, which is characterized by a monthly" production" curve. This object can be used to simulate a desalination plant or inter-basin transfers, for example. The groundwater and river supply available for any particular year is yet unsustainable; the maximum amount which can be delivered from the two sources is in the region of about 1.7 billion $m^3$ for the year 2024, while the total water supply that will be gotten from the two sources for the period 1993-2030 is in the region of 21.580 billion $m^3$ as against the water that will be demanded for the same period 28.680 billion $m^3$ of water quantities for HS City Water uses, thereby covering about 75.24% of the HS City water demand that will be satisfied, given all the previous scenarios computation. The high percentage of coverage was attributed to the sole connection of groundwater to HS City water usage. When we compute the overall demand from all scenarios and all demand nodes we obtain a total of 77.997 billion $m^3$ of water quantity and the supply that is delivered to offset the demand was a total of 39.22 billion $m^3$ accounting for only 50.28% of the total water demanded for 1993-2030 simulation model period. We are left with a problem of how to get atleast 38.777 billion $m^3$ (49.72%) of water resource for any sustainable city development in Heng Shui Municipality, to be distributed within the remaining period of this report plan simulation-modeling period.

## 5.7 Proposed Reservoirs Modeling

Base on the previous scenarios, we can see that the entire city of Heng Shui is plaque with serious water shortage, even though Heng Shui lake reservoir was in place, this lack will cause considerable hardship and lost in economy resource, since the city is 90% water dependence of water resource for irrigation purposes, hence for any meaningful and sustainable development to take place, planning of future water resource have to be done now to alleviate the impending danger hence the use of WEAP Simulation model , modeling reservoir to store up water resource that will be imported from various water resource such as Yellow River and Shi Jin River and upon completion, the water diversion project to the will alleviate substantial part of the water resource demands especially during lack and drought periods.

Note that in modeling the reservoir, we enter a demand priority of 99 to ensure that the reservoir will only be fill if all other needs are fulfilled, including downstream demand. The chart below shows the effect of increase reservoir storage. The storage capacity were increase to about 846.5 million $m^3$ that over 270% of the previous water supply, and we can conclude that, with this present storage, water sustainability could be achieved to some fair degree of acceptance and economy development.

Net evaporation needs to account for both rainfall and evaporation.

Table 5-13: The Supply data for the proposed Reservoir.

| STORAGE | Initial Storage m$^3$ | | Final Storage m$^3$ | Priority |
|---|---|---|---|---|
| | 246,500,000 | | 846,500,000 | 99 |
| VOLUME | Volume m$^3$ | 246,500,000 | 646,500,000 | 846,500,000 |
| CURVE | Elevation (m) | 10.0 | 70,0 | 100,0 |
| OPERATION | Top of conservation | Top of Buffer | Top of Inactive | Buffer coefficient |
| DATA | 40,000,000 m$^3$ | 30,000,000 m$^3$ | 2,000,000 m$^3$ | 0.78 |
| NET EVAPORATION | 32 mm per month | | | |

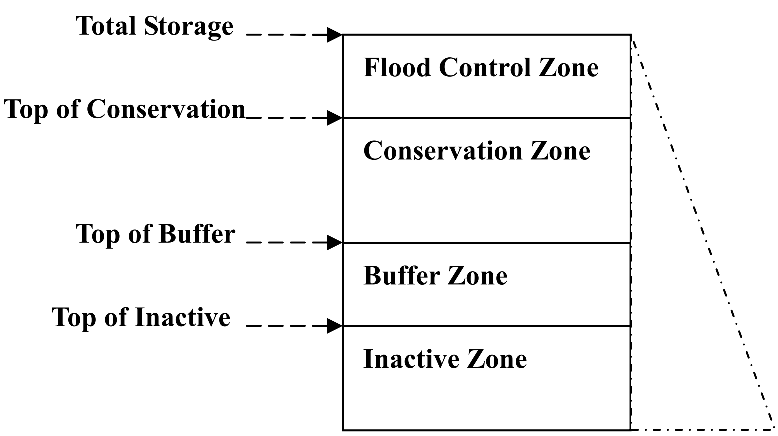



Figure 5-56: The various level of reservoir construction

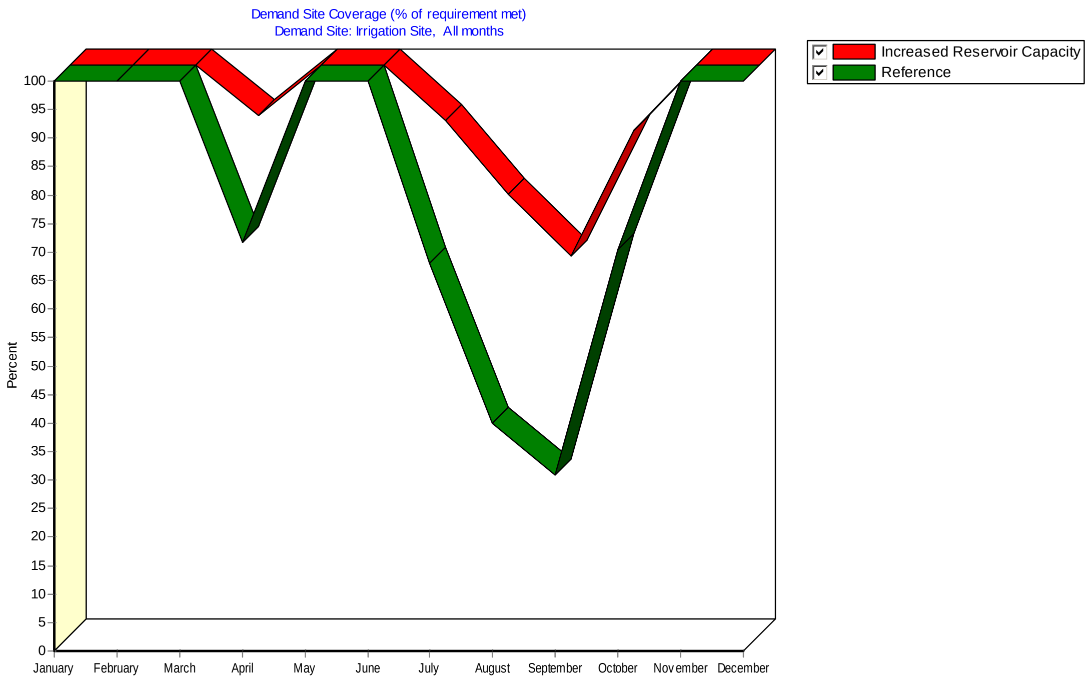



Figure 5-57: The effect of increased reservoir capacity on monthly percentage coverage made available to irrigation site demand.

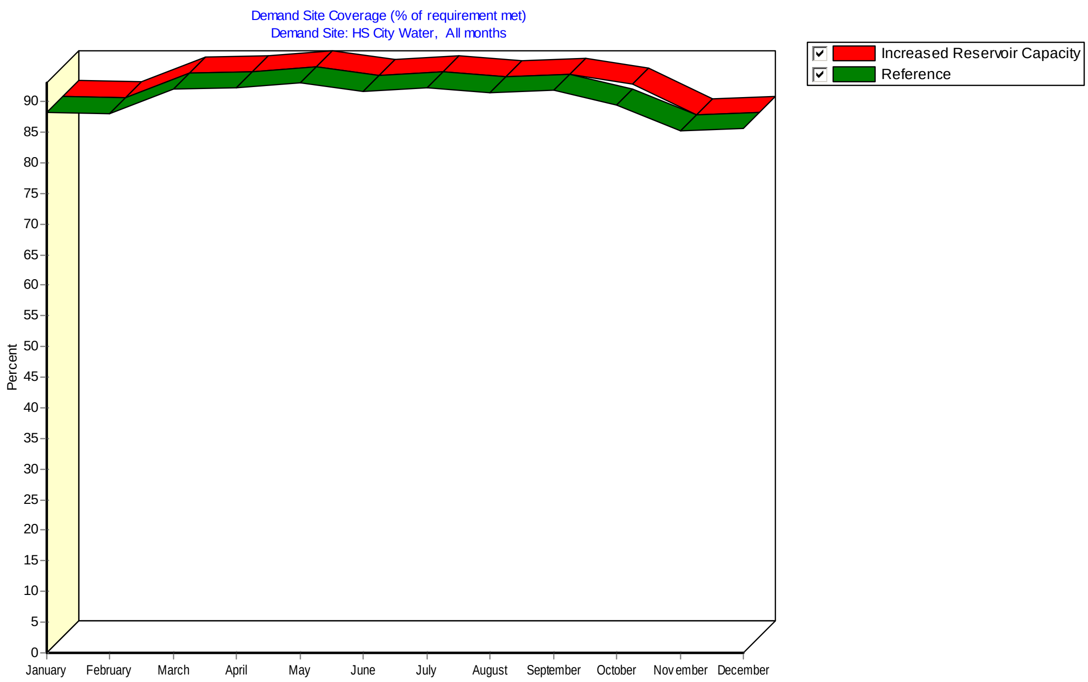



Figure 5-58: The effect of increased reservoir capacity on monthly percentage coverage made available to HS City demand.

Water demand coverage for city water use when the reservoir capacity was increased from it initial storage capacity of 246.5 to 846.5 million $m^3$

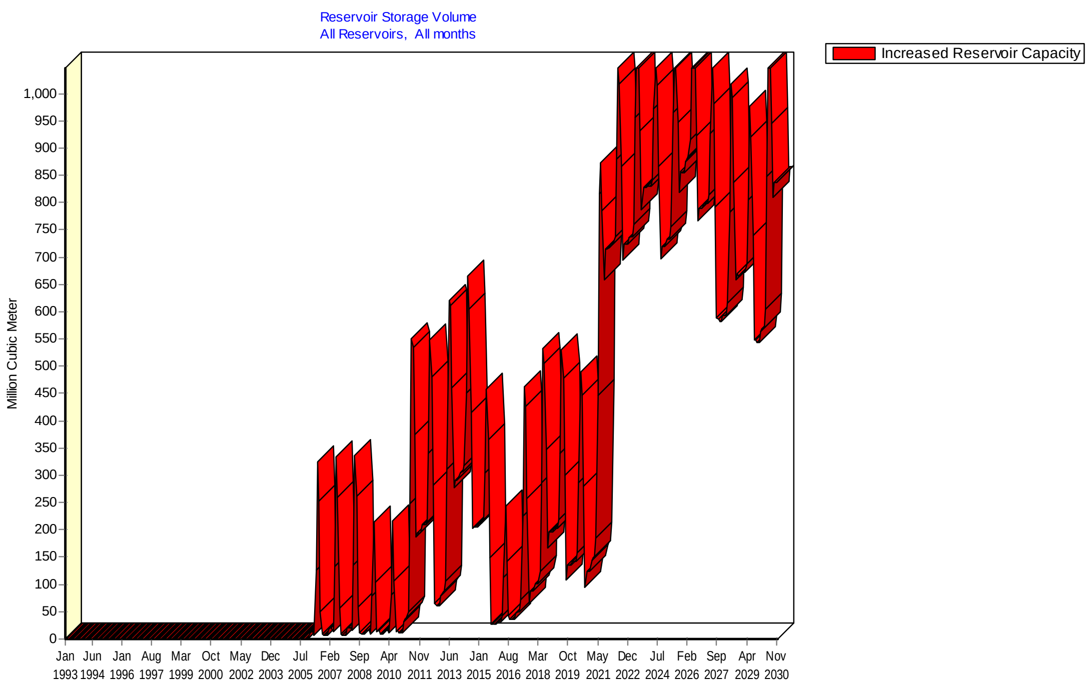



Figure 5-59: The annual increased reservoir capacity

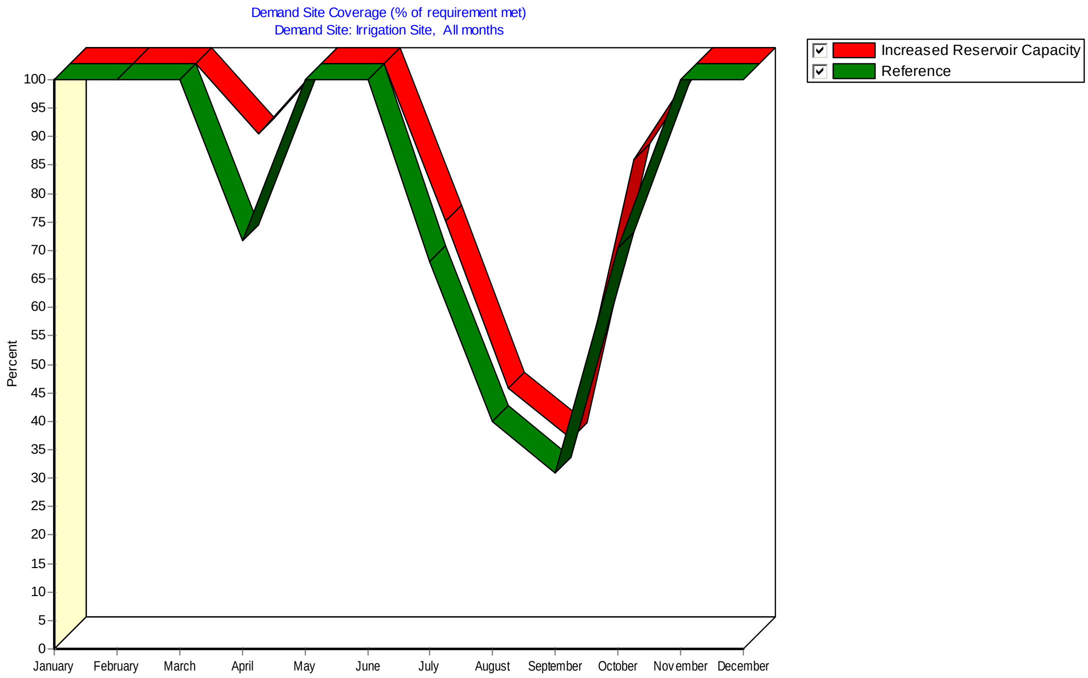



Figure 5-60: Showing the effect of buffer coefficient on monthly percentage coverage available to irrigation site demand

Here we can see the effect of the Curve elevation, Net evaporation, Top conservation, Top Buffer, Top of Inactive, and Buffer coefficient in the analysis, as it tends to reduce the water demand coverage as compare to the effect without buffer coefficient see Figure 5-57, 5-58 without buffer coefficient and Figure 5-60 with buffer coefficient, the buffer coefficient reduces the water availability and the rate at which water is made available to all demand site.

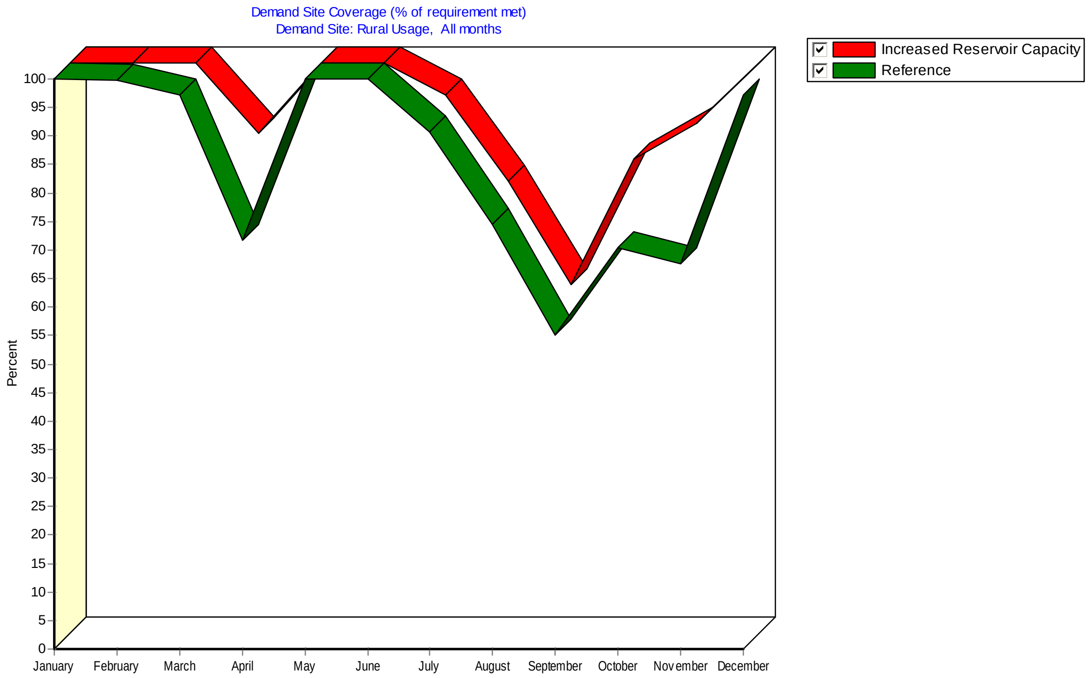



Figure 5-61: Showing the effect of buffer coefficient on monthly percentage coverage available to

rural demand site.

### 5.7.1 Modeling WWTP

The "Reach Length" tab displayed under the "Inflow and Outflow" screen is used only for groundwater-surface water interaction modeling. Since this interaction can occur along segment of the total reach length, it can differ from the total reach length. Note that the reach length data input here is not used for water quality modeling.

WEAP includes descriptive models of point source pollutant loadings that can simulate the impact of wastewater on receiving waters from demand sites and wastewater treatment plants. Water quality parameters that can be considered in WEAP include conservative substances, constituents that decay according to an exponential decay function, dissolved oxygen (DO) and biological oxygen demand (BOD) from point sources, and instream water temperature. Note that these parameters are not modeled in reservoirs, though; all reservoir outflow concentrations were inputed as data. In addition, water temperatures are not modeled in stream reaches or reservoirs; but these values also were inputed as data for reaches and reservoir outflows.

In the first-order DO model, water quality is simulated in Fu Dong Pai River, chosen via the WEAP user interface. Mass balance equations are written for each stream segment of the Fu Dong Pai River, with hydrologic inflows from rivers and groundwater sources automatically input to simulate the water balance and mixing of DO, BOD and other constituents along each reach. The river network is the same for the water resources and water quality simulations and assumes complete mixing.

First, all pollution loads into this river are calculated from demand site return flows, wastewater treatment plant return flows, groundwater inflows, headflows, upstream inflows, and other surface water inflows. WEAP assumes complete mixing of all inflows. As each constituent (other than conservative constituents) moves downstream, its decay is calculated.

### 5.7.2. Routing Pollution Generation

The pollution generated by a demand site (Domestic, Irrigation and Rural Usage) is carried in the wastewater return flows to wastewater treatment plants and receiving bodies of water. Wastewater flows distributed from these given demand sites to multiple destinations are assumed to have approximately the same concentrations. Therefore, the pollution streams flowing from a single source are proportional to the volume of flow. Thus, the amount of pollution that flows out of a demand site into a return flow link is a fraction of the pollution generated.

$$DSReturnLink\ PollInflow_{DS,Dest,p} = (\ DSOutflow\ Routing\ Fraction_{DS,Dest}1\ /\ \sum_{Dest} DSOutflow\ Routing\ Fraction_{DS,Dest}\ ) \times Monthly\ Poll\ Generated_{DS,p} \qquad 5\text{-}27$$

For example, if the routing fraction from Demand Site South Irrigation to South Aquifer was 27%, and the routing fraction from Irrigation South to the Fu Dong Pai River was 52% (with 21% of water consumed by the demand site), the fraction of Irrigation South's pollution that flow towards South Aquifer would be 0.27 / (0.27 + 0.52) = 0.34.

Some of the pollutant might decay or otherwise be lost as it passes through the return flow link. The pollution that flows out of the return flow link is a fraction of the inflow.

$$\textit{DSReturnLink PollOutflow}_{DS,Dest,p} = (1 - \textit{DSReturnLink PollDecrease Rate}_{DS,Dest,p}) \times \textit{DSReturnLink PollInflow}_{DS,Dest,p} \quad 5\text{-}28$$

**Groundwater Pollution**

Groundwater inflows to the river can bring pollution, specified by the concentration of each constituent in the groundwater inflow.

$$\textit{Groundwater Pollution Flow To Reach}_{GW,Rch,p,m} = \textit{Groundwater Flow To Reach}_{GW,Rch} \times \textit{Groundwater Pollution Concentration}_{GW,p,m} \quad 5\text{-}29$$

**Headflow Pollution**

River headflow can bring pollution, specified by the concentration of each constituent in the headflow.

$$\textit{Headflow Pollution River}_{River,p,m} = \textit{Headflow}_{River} \times \textit{Headflow Pollution Concentration}_{River,m,p} \quad 5\text{-}30$$

**Other Surface Water Inflow Pollution**

Any other surface water inflow to a reach can bring pollution, specified by the concentration of each constituent in the inflow.

$$\textit{Other SWInflow Pollution To Reach}_{Rch,p,m} = \textit{Other SWInflow To Reach}_{Rch} \times \textit{Other SWInflow Pollution Concentration}_{Rch,p,m} \quad 5\text{-}31$$

**Pollutant Loads**

The pollutant load to the Fu Dong Pai river node or reach is the sum of all the pollution from all connected demand site return flow links, treatment plant return flow links, groundwater inflows, headflows, upstream inflows, and other surface water inflows. WEAP assumes complete mixing of all inflows.

$$Pollution\ Load_{Node,p} = \sum_{DS} DSReturnLink\ PollOutflow_{DS,Node,p} + \sum_{TP} TPReturnLink$$
$$PollOutflow_{TP,Node,p} + \sum_{Des} GW\ Pollution\ Flow_{GW,Node,p} + Headflow\ Pollution_{River,p} +$$
$$Other\ SWInflow\ Pollution\ To\ Reach_{Rch,p} + UpstreamInflow\ Pollution\ To\ Reach_{Rch,p} \quad 5.32$$

**Surface Water Quality Modeling Overview**

WEAP can model the concentration of water quality constituents in a river using simple mixing, first-order decay, and built-in temperature, BOD and DO models. Note that water quality in reservoirs and groundwater is not modeled by WEAP, but the user can specify the water quality of outflows from them into river reaches.

**Simple Mixing**

Starting with the simplest assumptions, that the effects of diffusion and dispersion are negligible relative to the effects of advection, the stream may be represented as a plug-flow system. The initial concentration of a pollutant at the point of injection into the stream is calculated from a mass balance:

$$C = \frac{Q_w c_w + Q_r c_r}{Q_w + Q_r} \quad 5\text{-}33$$

Where:

C is the new concentration (mg/l)
$Q_w$ is the flow of wastewater discharged ($m^3$/time)
$C_w$ is the concentration of pollutant in the wastewater (mg/l)
$Q_r$ is the flow of receiving water ($m^3$/time)
$C_r$ is the concentration of pollutant in the receiving water (mg/l)

This is the simplest case of representing the spatial and temporal variation of pollution in a system. One possible candidate that could be modeled as a conservative pollutant would be salinity.

**Exponential First-Order Decay**

The modeling of the in-stream concentration below the point of discharge depends on the nature of the pollutant: for example, is the pollutant conservative and is settling a dominant process? For a conservative pollutant with negligible settling, the concentration can be determined simply from the equation above for $c_0$. For pollutants assumed to follow first order decay, the stream velocity and decay parameters must be estimated. For a known cross-sectional area, $A_c$ and flow rate, Q, the stream velocity U can be estimated as follows:

$$U = \frac{Q}{A_c} \qquad 5\text{-}34$$

$A_c$ is calculated based on user-entered data correlating stage to flow and width. The concentration of the pollutant at some distance downstream, L, from the point of discharge is the concentration as calculated in equation above for $c_0$, multiplied by a first order decay term, based on the decay parameter k (/day), as shown in the following equation.

$$c = c_o e^{-\frac{kL}{U}} \qquad 5\text{-}35$$

**Dissolved Oxygen and Biochemical Oxygen Demand**

First, the oxygen saturation OS for each segment is estimated as a function of water temperature T,

$$OS = 14.54 - (0.39T) + (0.01T^2) \qquad 5\ 36$$

And an analytical solution of the classic Streeter-Phelps model is used to compute oxygen concentrations from point source loads of BOD.

$$O = OS - \left(\frac{K_Q}{K_Q - K_Y}\right)\left(\exp^{-K_r(L/U)} - \exp^{-k_a(L/U)}\right)BOD_{IN} - \left((OS - O_{IN})\exp^{-k_a(L/U)}\right) \qquad 5\text{-}37$$

Where $k_d$=0.4; $k_a$ = 0.95; and $k_r$ = 0.4 are the decomposition, the reaction, and the re-aeration rates, respectively (1/day). L is the reach length (m), U the velocity of the water in the reach. $O_{IN}$ is the oxygen concentration (mg/l) at the top of the reach and $BOD_{IN}$ is the concentration of the pollutant loading (mg/l) at the top of the reach.

BOD removal is given as,

$$BOD = BOD_{IN}\left(\exp^{-K_{rBOD}(L/U)}\right) \qquad 5\text{-}38$$

The removal rate, $k_{rBOD}$, is influenced by several factors, including temperature, settling velocity of the particles, and water depth. Chapra (1997) provides an expression for $k_{rBOD}$ as,

$$K_{rBOD} = K_{d20}^{(1.047(T-20))} + \frac{V_5}{H} \qquad 5\text{-}39$$

Where T is the water temperature (in degrees Celsius), H is the depth of the water, and $V_s$ is the settling velocity. In addition, $k_{d20}$ is defined (at a reference temperature of 20 degrees Celsius) as,

$$K_{d20} = 0.3\left(\frac{H}{8}\right)^{-0.434} \qquad 0 \le H \le 2.4m$$

$$K_{d20} = 0.3 \qquad H > 2.4m$$

**Withdrawal Node**

Removing water from the river does not, in anyway change the concentration of the water, it just reduces the volume. Therefore, the concentration immediately below this node will be as flowed into the node from each reach.

**Demand Site**

Concentrations of pollution in demand site return flows does not depend on concentrations of inflows to the demand site. Therefore, the concentration of the river water supply is irrelevant.

The mass of each pollutant is calculated as,

$$Monthly\ Pollution\ Generated_{DS,p,m} = Demand\ Site\ ReturnFlow_{DS,m}\ x\ ReturnFlow\ Concentration_{DS,m,p} \qquad 5\text{-}40$$

**Salinity**

$$Treatment\ Plant\ PollOutflow_{TP,p} = (1 - Removal\ Rate_{TP,p})x\ Treatment\ Plant\ PollInflow_{TP,p} \qquad 5\text{-}41$$

DO is specified as a concentration, rather than a removal rate. Therefore, the inflow of DO is not used.

$$Treatment\ Plant\ PollOutflow_{TP,p} = Outflow\ Concentration_{TP,p}\ x\ Treatment\ Plant\ ReturnFlow_{TP,p} \qquad 5\text{-}42$$

**Return Flow Node**

Treated effluent from the wastewater treatment plant mixes with the river water, using the following weighted average:

$$c = \frac{Q_w C_w + Q_r C_r}{Q_w + Q_r} = \frac{M_w + Q_r C_r}{Q_w + Q_r} \qquad 5\text{-}43$$

**Water Temperature**

Water temperature for a river node is computed using simple mixing--a weighted average of the water temperatures in the inflows from upstream, tributaries, return flows, and groundwater inflows.

As water flows downstream, the water temperature can change due to gains of heat from net solar short-wave radiation and atmospheric long-wave radiation, and losses of heat due to conduction, convection and evaporation.

The volume for a reach is defined by its length and average cross sectional area, and the assumption of steady state during the time step. A heat balance equation is written for each reach on the river.

$$\frac{dT}{dt} = \frac{Q_i}{V}T_i + \frac{R_n}{\rho C_p H} + \left( \frac{\sigma (T_{air} + 27)^4 a (e_{air})^{1/2}}{\rho C_p H} \right) - \frac{Q_i}{V}T_{i+1} - \frac{\varepsilon\sigma (t_{i+1} + 273)^4}{\rho C_p H} - \frac{f(u)(T_{i+1} - T_{air})}{\rho C_p H} - \frac{g(u)D}{\rho C_p H} \qquad 5\text{-}44$$

Where the first term on the right-hand side is the upstream heat input to the stream segment with constant volume, V ($m^3$) expressed as a relationship of flow, $Q_i$ ($m^3$/time) and temperature, $T_i$ at the upstream node. The second term is the net radiation input, Rn, to the control volume with density rho, and $C_p$ the specific heat of water and H (m), the mean water depth of the stream segment. The third term is the atmospheric long-wave radiation into the control volume, with the steffan-boltzman constant, $T_{air}$ the air temperature (C), *a*, a coefficient to account for atmospheric attenuation and reflection and the air vapor pressure, $e_{air}$. The fourth term is the heat leaving the control volume, while the fifth term is the long-wave radiation of the water that leaves the control. The sixth and seventh terms are the conduction of heat to the air and the removal of heat from the river due to evaporation. The terms f(u) and g(u) are wind functions, and D is the vapor pressure deficit. The temperature, $T_{i+1}$ are solved for the downstream node with a fourth-order runga-kutta and are the boundary condition temperature for the next reach (after mixing of any other inflows into the downstream node is considered).

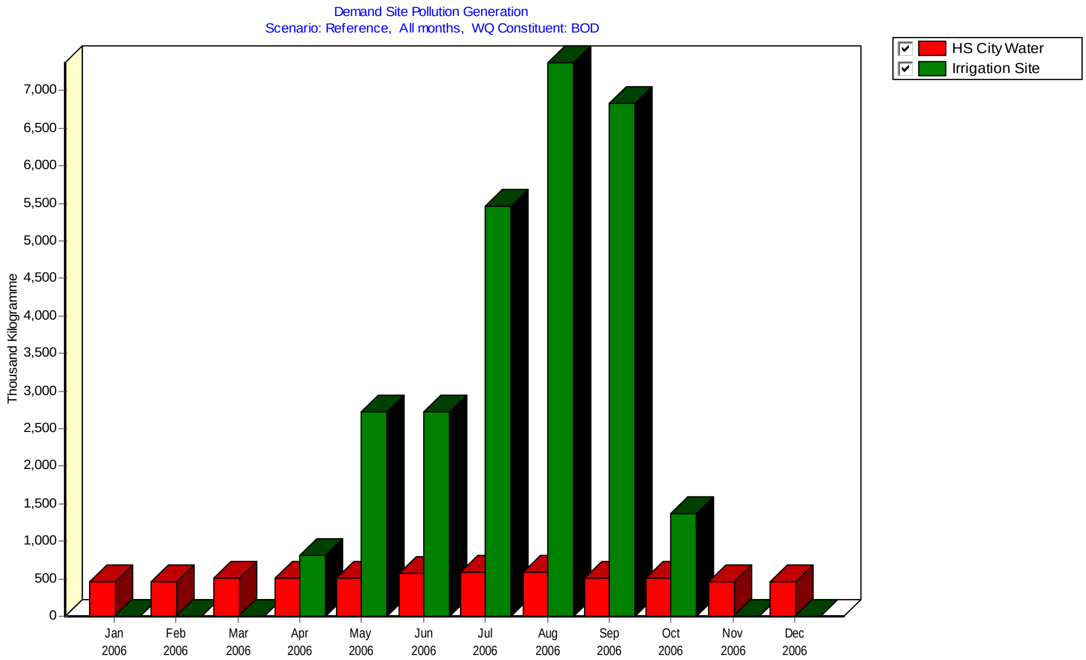



Figure 5-62: The demand site Pollution generation for the year 2006,

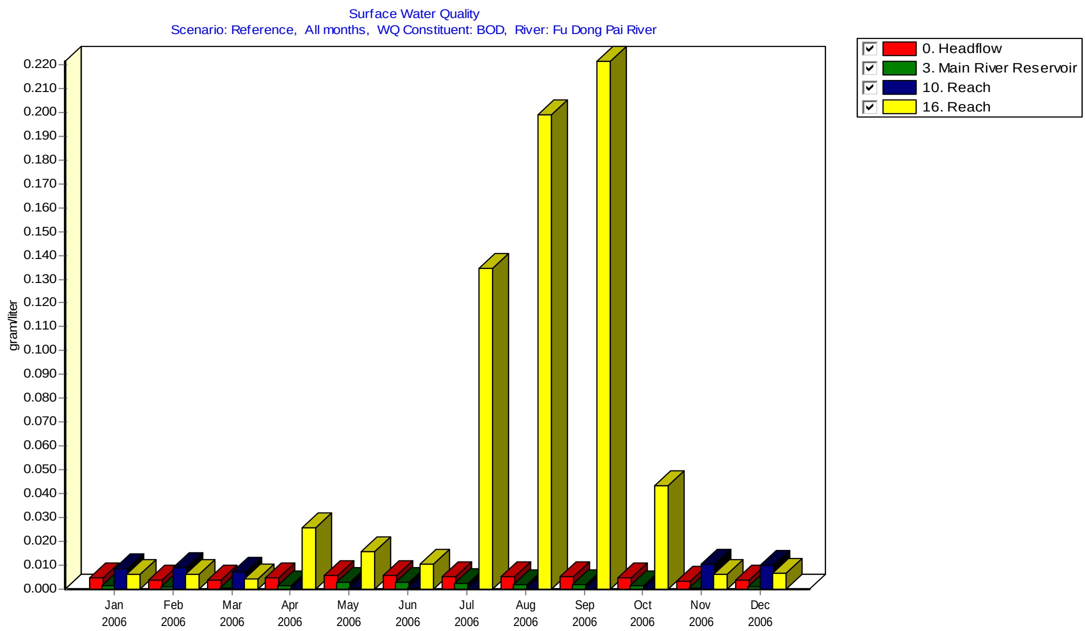



Figure 5-63: The surface water quality for irrigation (2006).

**Key**

0--Below Fu Dong Pai River Headflow.

3--Below Main River Resrvoir (Heng Shui Lake)

10--Below Return Flow Node i.e from the city

16--Below Return Flow Node 3 i.e from Rural Usage

**Note:** that Pollution Generation for Agriculture is constrained to the spring and summer months when the farming is active

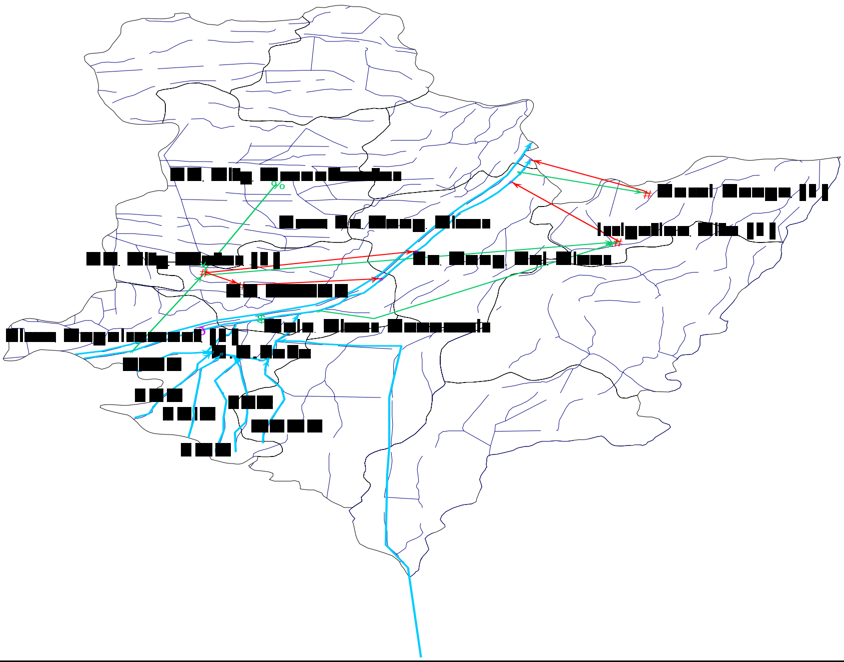


Figure 5-64: Adding WWTP to the schematic model simulation

If only part of the wastewater is treated through the WWTP, there are two modeling possibilities. One is to limit the Daily Capacity to whatever amount can actually be treated (80,000 $m^3$/day). In this case the wastewater in excess will be discharged without treatment. In this case, the share of untreated wastewater is not constant, but depends on the total flow. Another solution is to create an additional return flow going from the demand site straight to the river, bypassing the WWTP. In this case, setting the return flow routing shares accordingly can set the WWTP a constant share to by-pass. A combination of both methods is also possible

Comparing the results of the BOD in the “Wastewater Treatment Plant Added” scenario, and the “Reference scenario”(without a wastewater treatment plant).

**Water Quality Constraints**

If maximum water quality concentrations on demand site inflow from supplies have been set, then additional water quality constraints are created. The basic relationship states that the weighted average mixed concentration from all supplies must not exceed the maximum allowed concentration.

$$(Q_1 C_1 + Q_2 C_2 + \ldots) / (Q_1 + Q_2 + \ldots) \le C_{max} \qquad 5\text{-}45$$

This can be transformed into

$$Q_1 (1 - C_1 / C_{max}) + Q_2 (1 - C_2 / C_{max}) + \ldots \ge 0 \qquad 5\text{-}46$$

Where $Q_i$ is the flow into the demand site from sources i, $C_i$ is the concentration of source i in the previous timestep, and $C_{max}$ is the maximum allowed concentration. Because the water quality calculations in the river are inherently non-linear, the concentrations used in the equation above must come from the previous time step. Thus, the $(1 - C_i / C_{max})$ terms are constants, and this equation (Eq. 5-46) is a suitable form for a LP constraint.

$C_2$ is the river BOD concentration (10 mg/l), and $C_{max}$ is the demand site's concentration.

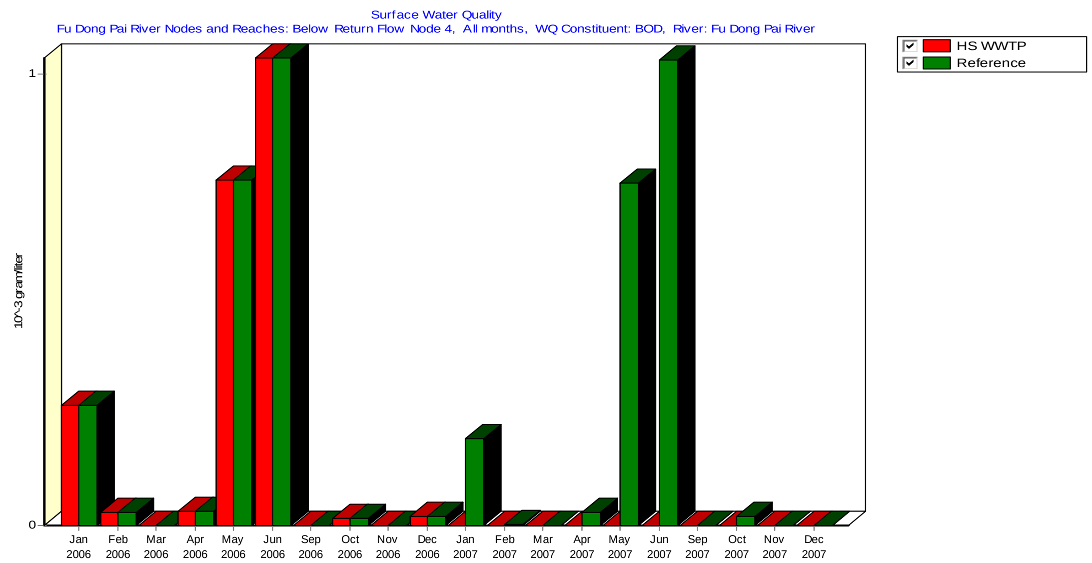



Figure 5-65a: The surface return flow water quality (BOD) for the city (2006 and 2007)

This graphical illustration of water quality when less than 20% of the water return flow is directed to the WWTP, the resulted polluted water gotten from irrigation practices and few domestic waste was seen to be completely treated with the introduction of efficient but low capacity WWTP being effective in the year 2007, needless to say that, the water stream will yet contained large amount of pollutant since 80% of the untreated water is allow to return back to the River. Contrary we can notice the over utilization of WWTP by sending the absolute wastewater to be treated, we can see that, the effluent untreated water is still available in spite of the WWTP.

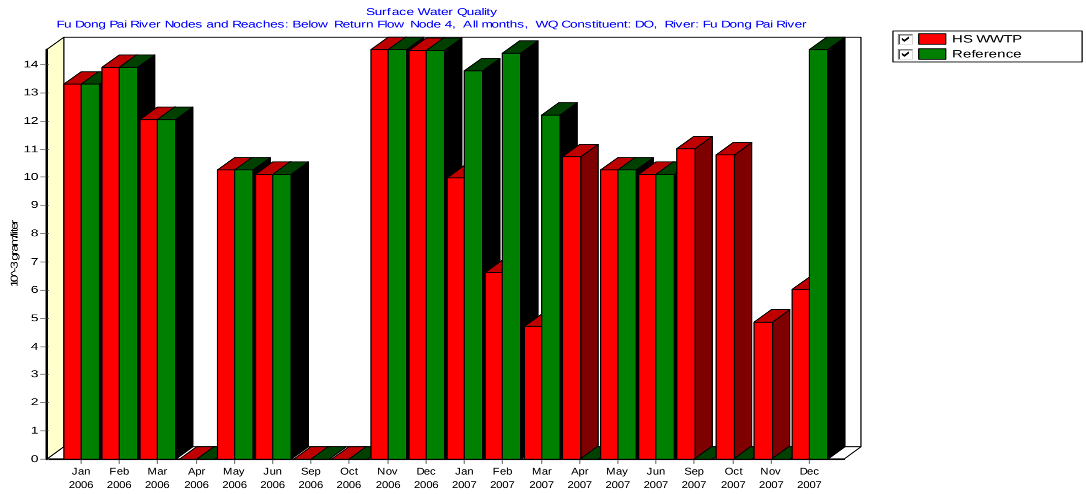



Figure 5-65b: The surface return flow water quality (DO) for the city (2006 and 2007)

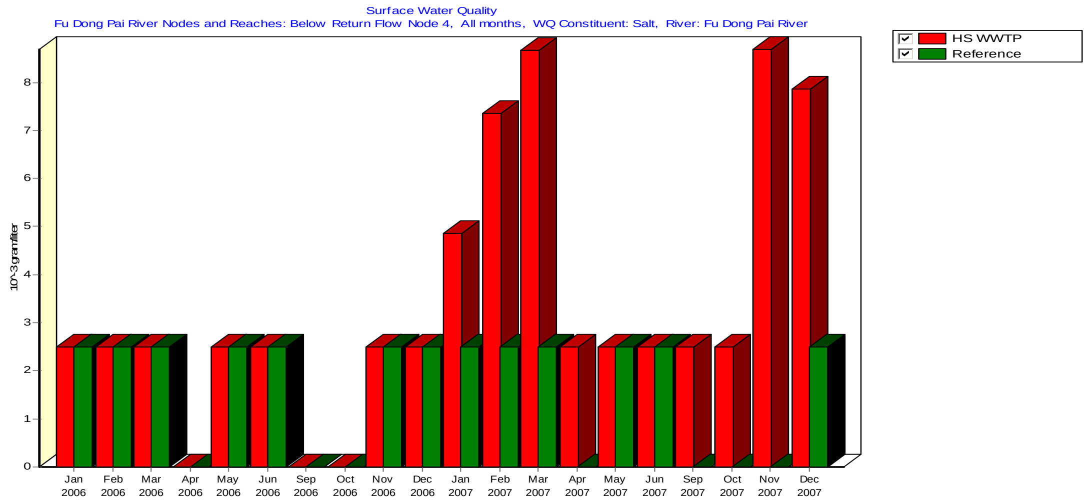



Figure 5-65c:The surface return flow water quality (Salt) for the city (2006 and 2007)

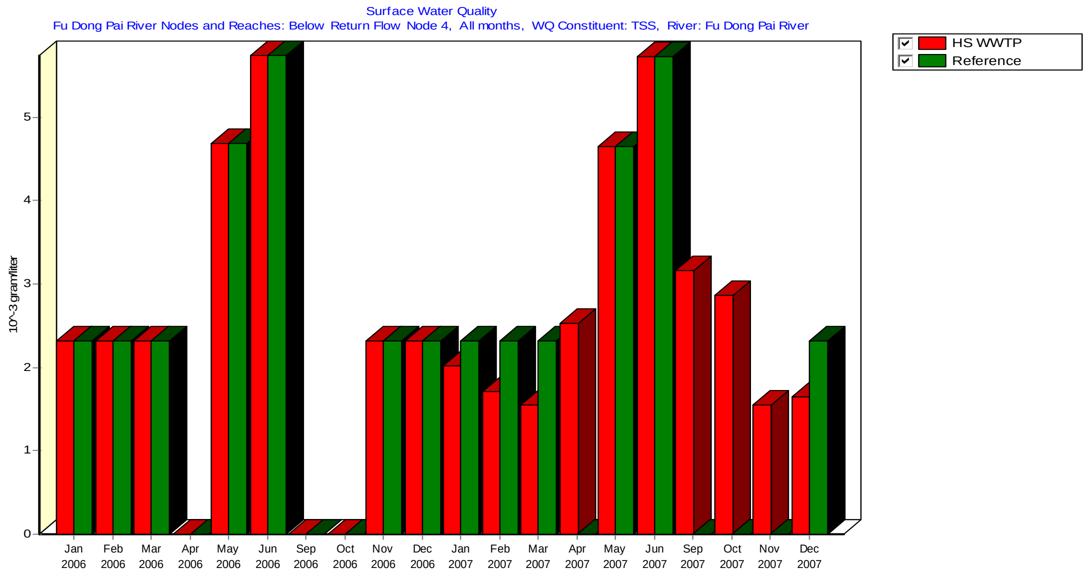



Figure 5-65d:The surface return flow water quality (TSS) for the city (2006 and 2007)

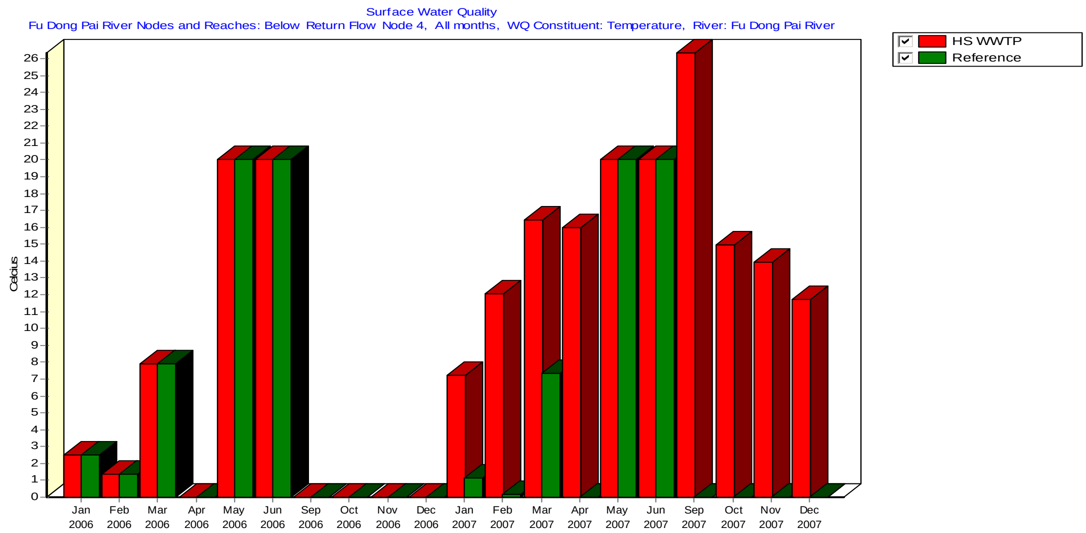



Figure 5-65e: The surface return flow water quality (Temp) for the city (2006 and 2007)

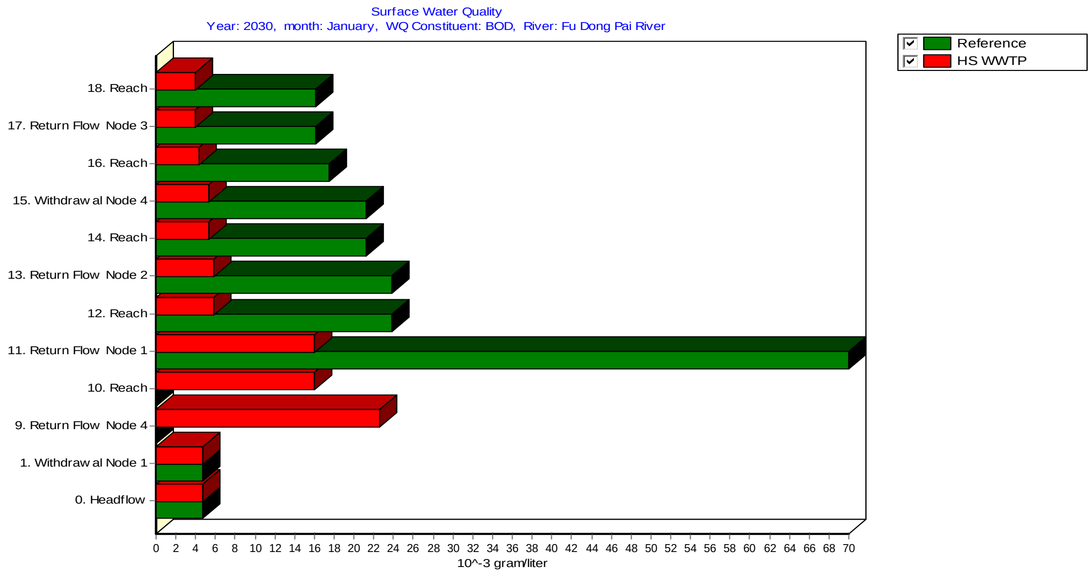



Figure 5-65f: The surface return flow water quality (BOD) for all reach (Jan. 2030)

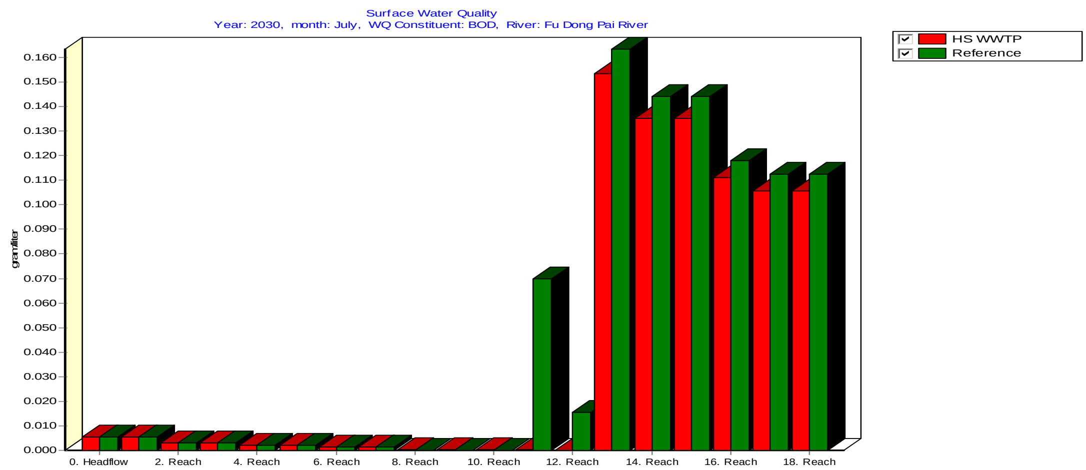


Figure 5-66:The surface return flow water quality (BOD) for all reach (July 2030)

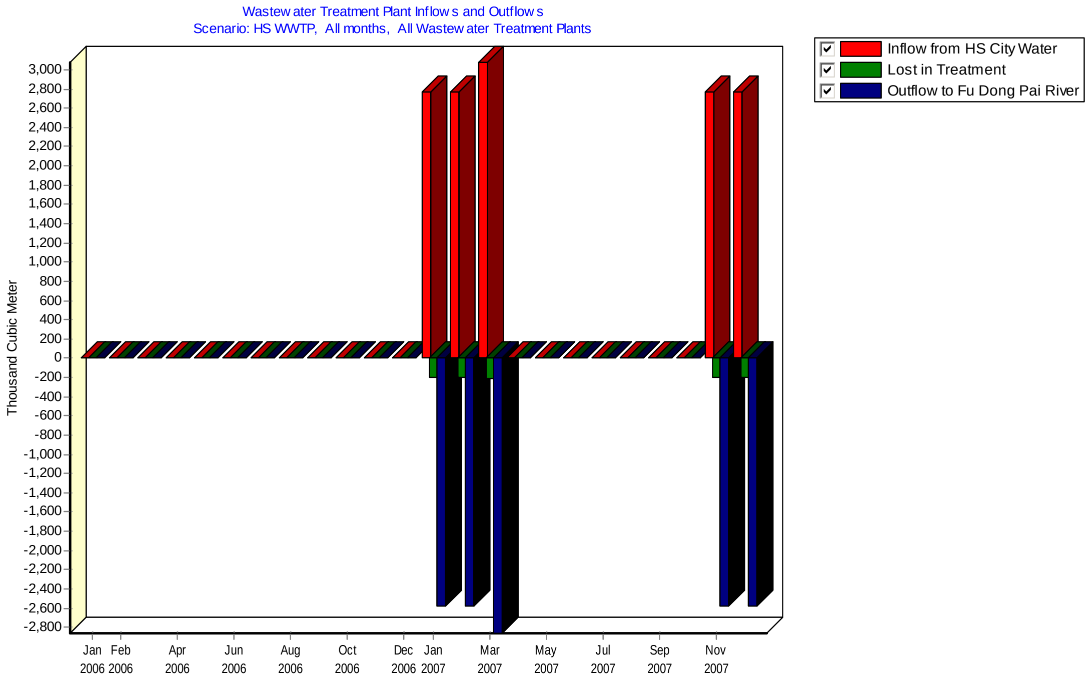



Figure 5-67: The WWTP Inflows and Outflows (2030)

In this type of chart, the outflows are represented as negative values and the inflows are positive values. Note also that the "Lost in Treatment" represents the flow that is consumed- a consumption rate of 5% was input in the data view for the treatment plant

## 5.8 Modeling Catchments:

### 5.8.1 The Rainfall Runoff Model

**Runoff, Infiltration and Irrigation Overview**

There is a choice among three methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall Runoff and (2) Irrigation Demands Only versions of the FAO Crop Requirements Approach, and (3) the Soil Moisture Method. The choice of method depends on the level of complexity desired for representing the catchment processes and data availability.

Of these three methods, the Irrigation Demands Only method is the simplest. It uses crop coefficients to calculate the potential evapotranspiration in the catchment, and then determines any irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet. It does not stimulate runoff or infiltration processes.

The Rainfall Runoff method also determines evapotranspiration for irrigated and rainfed crops using crop coefficients. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via catchment links.

The Soil Moisture Method is the most complex of the three methods; it represents the catchment with two soil layers, as well as the potential for snow accumulation. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. Baseflow routing to the river and soil moisture changes are simulated in the lower soil layer. Correspondingly, the Soil Moisture Method requires more extensive soil and climate parameterization to simulate these processes. One can also link groundwater nodes to catchments simulated with the Soil Moisture Method. In this case, the lower soil layer is ignored and precipitation that passes through the upper soil layer is routed to the groundwater node rather than baseflow and increases in soil moisture in this lower layer.

**FAO ReQuirement**

FAO crop requirements are calculated assuming a demand site with simplified hydrological and agro-hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rainfall agriculture. Obviously non-agricultural crops can be included as well. The following equations were used to implement this approach where subscripts $_{LC}$ is land cover, $_{HU}$ is hydro-unit, $_{I}$ is irrigated, and $_{NI}$ is non-irrigated:

$$Precip\ Available\ Fo\ rET_{LC} = Precip_{HU} * Area_{LC} * 10^{-5} * Precip\ Effective_{LC}$$

$$ETpotential_{LC} = ETreference_{HU} * Kc_{LC} * Area_{LC} * 10^{-5} \qquad 5\text{-}47$$

$$Precip\ Shortfall_{LC,I} = \mathrm{Max}\ (\ 0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I}) \qquad 5\text{-}48$$

$$SupplyRequirement_{LC,I} = (1\ /\ IrrFrac_{LC,I}\ ) * Precip\ Shortfall_{LC,I} \qquad 5\text{-}49$$

$$Supply\ Requirement_{HU} = {}_{LC,I}\ Supply\ Requirement_{LC,I} \qquad 5\text{-}50$$

The above four equations are used to determine the additional amount of water (above the available precipitation) needed to supply the evapotranspiration demand of the land cover (and total hydro unit) while taking into account irrigation efficiencies.

Based on the system of priorities, the following quantities can be calculated:

$$Supply_{HU} = \text{Calculated by WEAP allocation algorithm} \qquad 5\text{-}51$$

$$Supply_{LC,I} = Supply_{HU} * (\ Supply\ Requirement_{LC,I} / Supply\ Requirement_{HU}\ ) \quad 5\text{-}52$$

$$ETActual_{LC,NI} = \text{Min}\ (ETpotential_{LC,NI}\ ,\ Precip\ Available\ ForET_{LC,NI}\ ) \quad 5\text{-}53$$

$$ETActual_{LC,I} = \text{Min}\ (ETpotential_{LC,I}\ ,\ Precip\ Available\ For\ ET_{LC,I}\ )$$

$$+\ IrrFrac_{LC,I} * Supply_{LC,I} \quad 5\text{-}54$$

$$EF_{LC} = ETActual_{LC} / ETpotential_{LC} \quad 5\text{-}55$$

As a result, the actual yield can be calculated with the following equation:

$$ActualYield_{LC} = PotentialYield_{LC} * \text{Max}\ (0, (1 - YieldResponseFactor_{LC}$$

$$* (1 - EF_{LC}))) \quad 5\text{-}56$$

Runoff to both groundwater and surface water can be calculated with the following equations:

$$Runoff_{LC} = \text{Max}\ (0, Precip\ Available\ For\ ET_{LC} - ETpotential_{LC})$$

$$+ (Precip_{LC} * (1 - PrecipEffective_{LC})) + (1 - IrrFrac_{LC,I}\ ) * Supply_{LC,I} \quad 5\text{-}57$$

$$RunoffToGW_{HU} = \quad {}_{LC}\ (Runoff_{LC} * Runoff\ To\ GW\ Fraction_{LC}) \quad 5\text{-}58$$

$$Runoff\ To\ Surface\ Water_{HU} = {}_{LC}\ (Runoff_{LC} * (1 - RunoffToGWFraction_{LC}\ )\ ) \quad 5\text{-}59$$

Table 5-14: Monthly runoff from precipitation.

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference | 0.4 | 0.9 | 2.6 | 3.5 | 12.8 | 52.2 | 49.8 | 900.9 | 64.8 | 15.4 | 7.1 | 12.3 | 1122.8 |

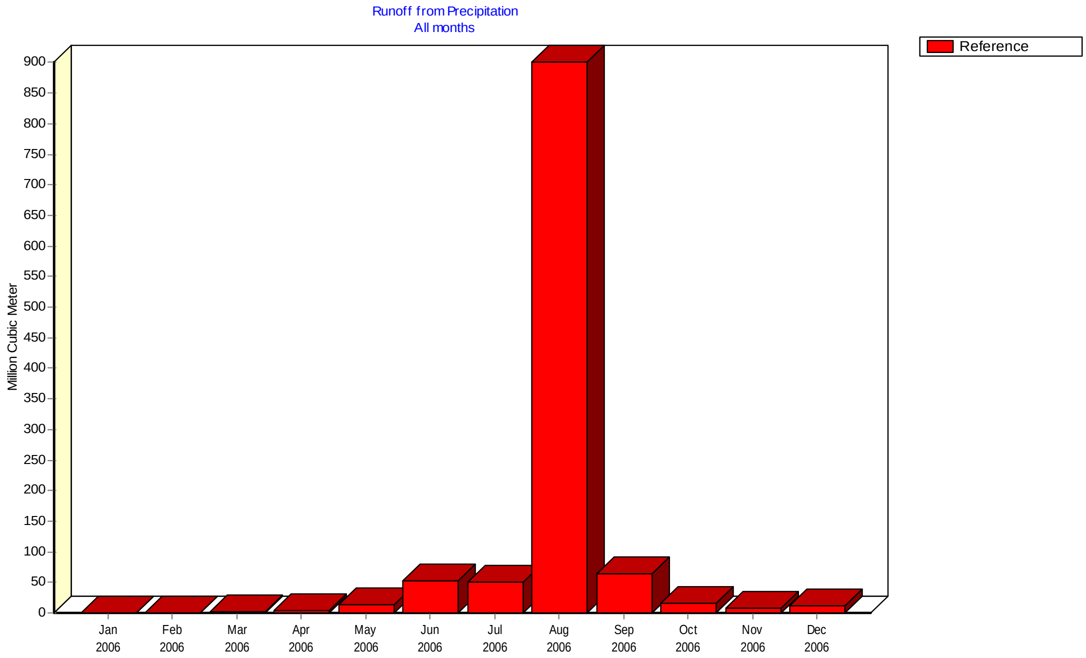



Figure 5-68: The "Runoff from Precipitation" to the Main River

### 5.8.2 The Soil Moisture Model

The purpose of this transmission link is to allow supplying irrigated areas with from the river in case rainfall is insufficient.

Land Class Inflow and Outflows represents in a very detailed manner the water balance for each land use class. In this class Inflow and Outflow, various detailed water balance were taken into consideration by the WEAP model, such classes are Surface Runoff, Snow Well, Snow Accumulation, Precipitation, Irrigation, Interflow, Increase Soil Moisture, Evapotranspiration, Decrease in Soil Moisture, Base Flow.

This one dimensional, 2-compartment (or "bucket") soil moisture accounting scheme is based on empirical functions that describe evapotranspiration, surface runoff, sub-surface runoff (i.e., interflow), and deep percolation for a watershed unit (see Figure 5-69). This method allows for the characterization of land use and/or soil type impacts to these processes. The deep percolation within the watershed unit can be transmitted to a surface water body as baseflow or directly to groundwater storage if the appropriate link is made between the watershed unit node and a groundwater node.

A watershed unit can be divided into N fractional areas representing different land uses/soil types, and a water balance is computed for each fractional area, j of N. Climate is assumed uniform over each sub-catchment, and the water balance is given as,

$$Rd_j \frac{dz_{1,j}}{dt} = P_e(t) - PET(t)k_{1,j}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^2}{3}\right) - P_e(t)z_{1,j}^{LAI_1} - (1-f_j)k_j z_{1,j}^2 - f_j k_j z_{1,j}^2$$

Where $z_{1,j}$ = [1,0] is the relative storage given as a fraction of the total effective storage of the root zone, $Rd_j$ (mm) for land cover fraction, j. The effective precipitation, $P_e$, includes snowmelt from accumulated snowpack in the sub-catchment, where $m_c$ is the melt coefficient given as,

$$M_c = \begin{cases} 0 & T_i < T_s \\ 1 \quad \text{if} & T_i > T_l \\ \dfrac{T_i - T_s}{T_l - T_s} & T_s \le T_i \le T_l \end{cases} \qquad 5\text{-}61$$

Where $T_i$ is the observed temperature for month *i,* and $T_l$ and $T_s$ are the melting and freezing temperature thresholds. Snow accumulation, $Ac_i$, is a function of $m_c$ and the observed monthly total precipitation, $P_i$, by the following relation, observed monthly total precipitation, $P_i$, by the following relation,

$$Ac_i = Ac_{i-1} + (1 - m_c)P_i \qquad 5\text{-}62$$

With the melt rate, $m_r$, defined as,

$$M_r = Ac_i m_c \qquad 5\text{-}63$$

The effective precipitation, $P_e$, is then computed as

$$P_e = P_i m_c + m_r \qquad 5\text{-}64$$

In Eq. 5.60, PET is the Penman-Montieth reference crop potential evapotranspiration, where $k_{c,j}$ is the crop/plant coefficient for each fractional land cover. The third term represents surface runoff, where $LAI_j$ is the Leaf Area Index of the land cover. Lower values of $LAI_j$ lead to more surface runoff. The third and fourth terms are the interflow and deep percolation terms, respectively, where the parameter $k_{s,j}$ is an estimate of the root zone saturated conductivity (mm/time) and $f_j$ is a partitioning coefficient related to soil, land cover type, and topography that fractionally partitions water both horizontally and vertically. Thus total runoff, RT, from each sub-catchment at time t is,

$$RT(t) = \sum_{j=1}^{N} A_j \left( P_e(t) z_{1,j}^{LAI_1} - (1 - f_j) k_j z_{1,j}^2 \right) \qquad 5\text{-}65$$

For applications where no return flow link is created from a catchment to a groundwater node, baseflow emanating from the second bucket will be computed as:

$$S_{\max}\frac{dz_2}{dt}=\left(\sum_{j=1}^{N}f_j k_j z_{1,j}^2\right)-k_2 z_2^2 \qquad \text{5-66}$$

Where the inflow to this storage, $S_{max}$ is the deep percolation from the upper storage given in Eq. 5.60, and $K_{s2}$ is the saturated conductivity of the lower storage (mm/time), which is given as a single value for the catchment and therefore does not include a subscript, *j*. Equations 5.60 and 5.65 are solved using a predictor-corrector algorithm.

When an alluvial aquifer is introduced into the model and a runoff/infiltration link is established between the watershed unit and the groundwater node, the second storage term (given by Eq. 6.65) is ignored, and recharge R (volume/time) to the aquifer is

$$R=\sum_{j=1}^{N}A_j\left(f_j k_j z_{1,j}^2\right) \qquad \text{5-67}$$

Where A is the watershed unit's contributing area. The stylized aquifer characterizes the height of the water table relative to the stream, where individual river segments can either gain or lose water to the aquifer

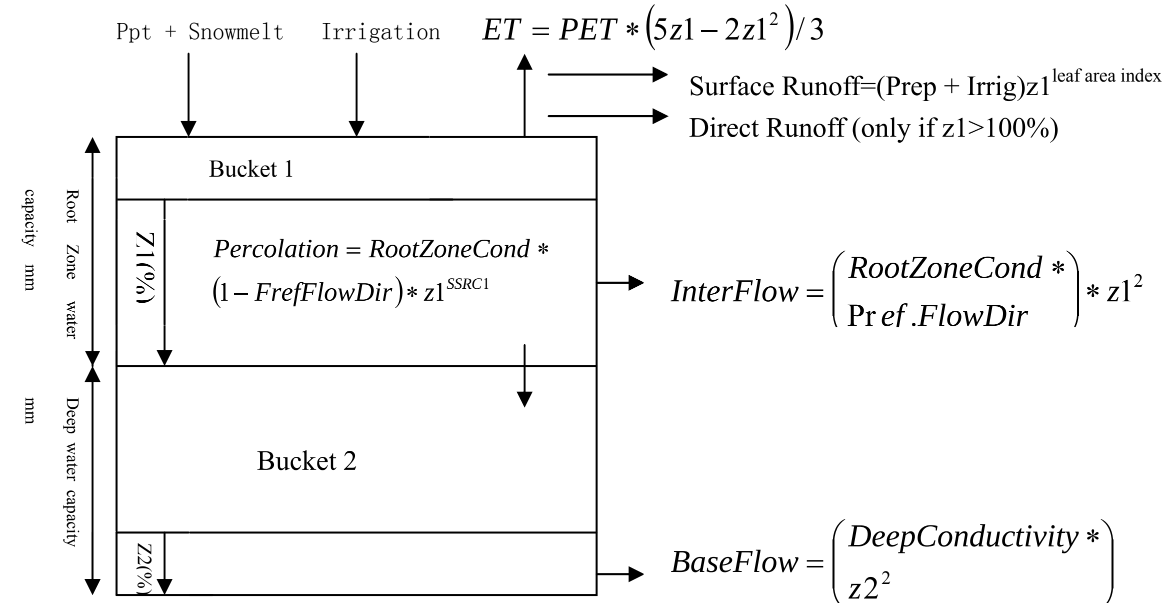



Figure 5-69: Conceptual diagram and equations incorporated in the Soil Moisture mode

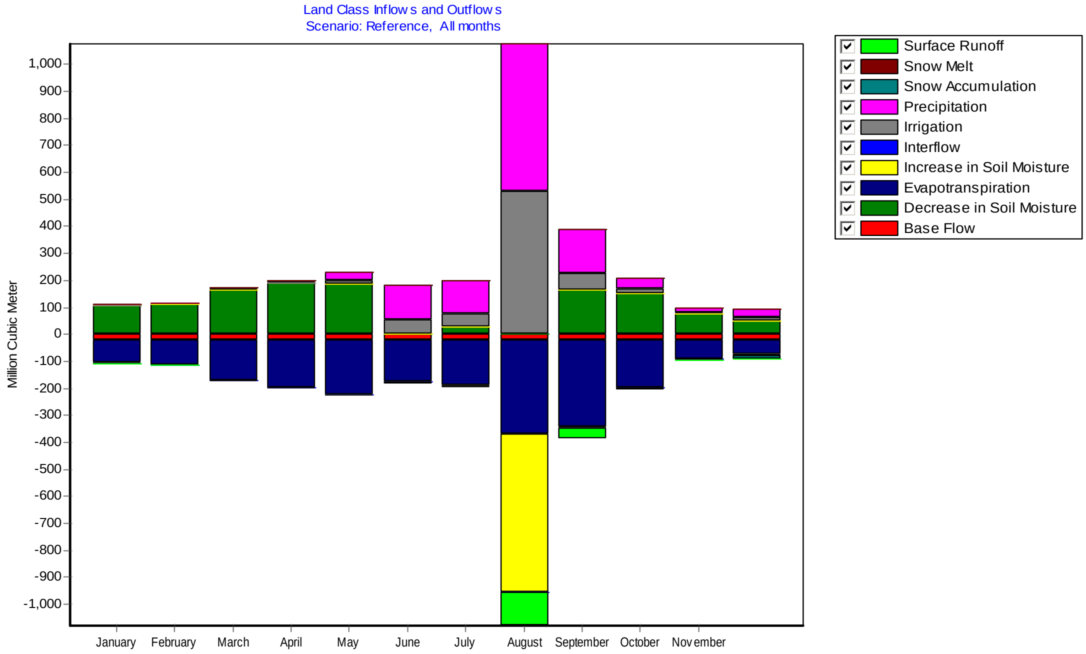



Figure 5-70: The land class Inflows and Outflows

You can also look at such parameter as "Soil Moisture in the upper bucket" (Relative Soil Moisture 1%) or "Flow to the River Full Irrigation" which displays the water flowing to the river, including the irrigation water in excess

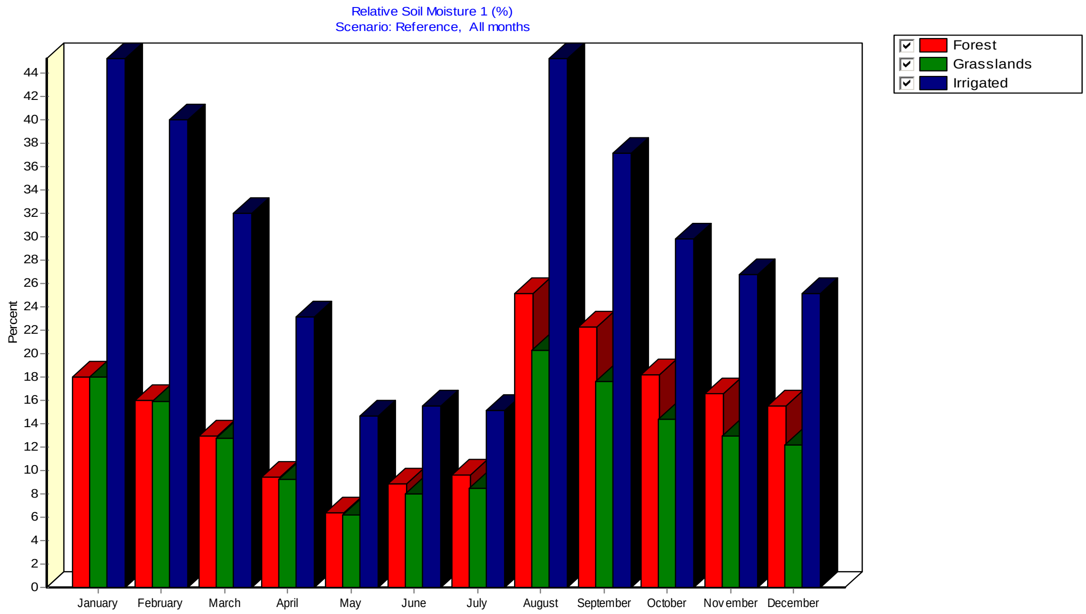



Figure 5-71: The Relative Soil Moisture for all agricultural classes..

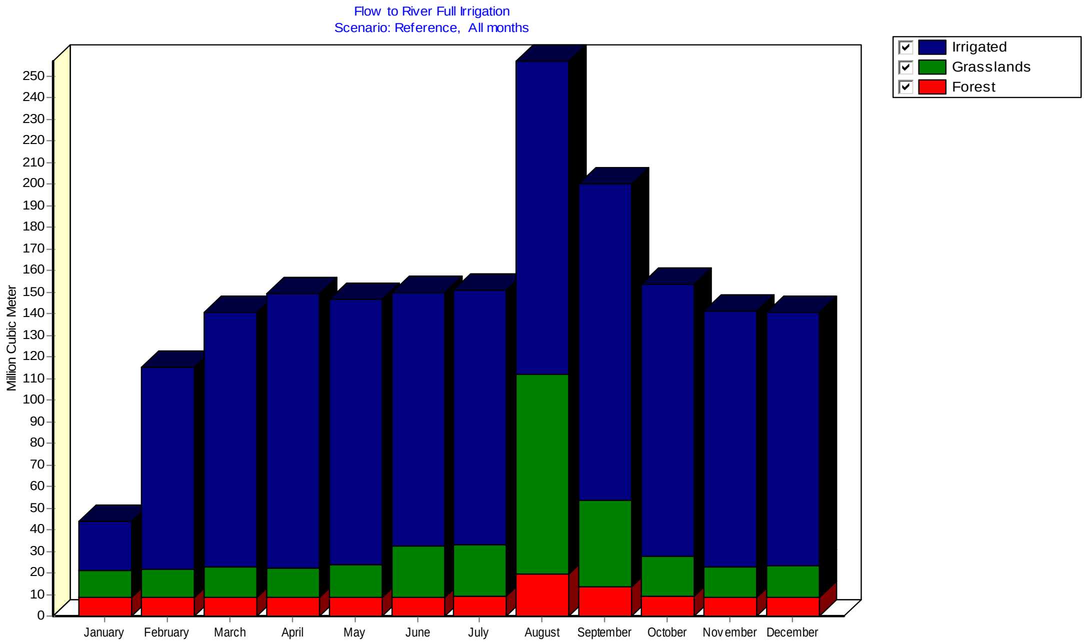



Figure 5-72: The Flow to River full Irrigation for all Agricultural classes

As we can see from the series of graphs, Irrigation happens largely from the month of March to December. Soil Moisture in the first bucket is rather constant at 47% to 52% throughout the year in the irrigated land class, which is consistent with the lower threshold we had set. The largest contribution of flow from the catchment to the river is from the irrigated land class

### 5.8.3 Simulating Surface Water-Groundwater Interaction

In many watersheds, surface waters and groundwater are hydraulically connected. A stream can contribute to groundwater recharge (i.e., a losing stream) or can gain water from the aquifer (i.e., a gaining stream) depending on the level of groundwater in the aquifer. Groundwater levels respond to natural recharge from precipitation, but can also be influenced by irrigation in the watershed, where a portion of this water may recharge the aquifer rather than be taken up by the target crop.

To simulate groundwater interactions with surface waters, a stylized representation of the system can be used. Groundwater can be represented as a wedge that is symmetrical about the surface water body, such as a river; recharge and extraction from one side of the wedge will therefore represent half the total rate.

Total groundwater storage is first estimated using the assumption that the groundwater table is in equilibrium with the river; equilibrium storage for one side of the wedge, $GS_e$, can be given as,

$$GS_e = (h_d)(l_w)(A_d)(S_y) \quad \text{5-68}$$

Where $h_d$ (m) represents the distance that extends in a direction horizontally and at a right angle to the stream, $l_w$ (m) is the wetted length of the aquifer in contact with the stream, $S_y$ is the specific yield of the aquifer, and $A_d$ is the aquifer depth at equilibrium. An estimate of the height above which the aquifer lies or is drawn below the equilibrium storage height is given by $y_d$, so the initial storage GS(0) in the aquifer at t =0 is given as,

$$GS(0) = GS_e + (y_d)(h_d)(l_w)(S_y) \quad 5\text{-}69$$

The vertical height of the aquifer above or below the equilibrium position is given as,

$$y_d = \frac{GS - GS_e}{(h_d)(l_w)(S_y)} \quad 5\text{-}70$$

The more the water table rises relative to the stream channel, the greater the seepage becomes to the stream. The more the water table falls relative the stream channel, the greater the loss of water from the stream channel to the aquifer. Total seepage from both sides of the river ($m^3 / time$) is defined by,

$$S = 2\left(k_s \frac{y_d}{h_d}\right)(l_w)(d_w) \quad 5\text{-}71$$

Where $K_s$ (m/time) are an estimate of the saturated hydraulic conductivity of the aquifer and $d_w$ is an estimate of the wetted depth of the stream, which is time invariant. The wetted depths, together with the wetted length, approximate the area through which the seepage takes place. The saturated hydraulic conductivity controls the rate at which water moves toward or away from this seepage area. Once seepage is estimated, the groundwater storage at the end of the current time step is estimated as,

$$GS_{(i)} = GS_{(i-1)} + 0.5(R - E - S) \quad 5\text{-}72$$

Where E is the anthropogenic extraction from the aquifer that is associated with meeting water demand and R is recharge from precipitation.

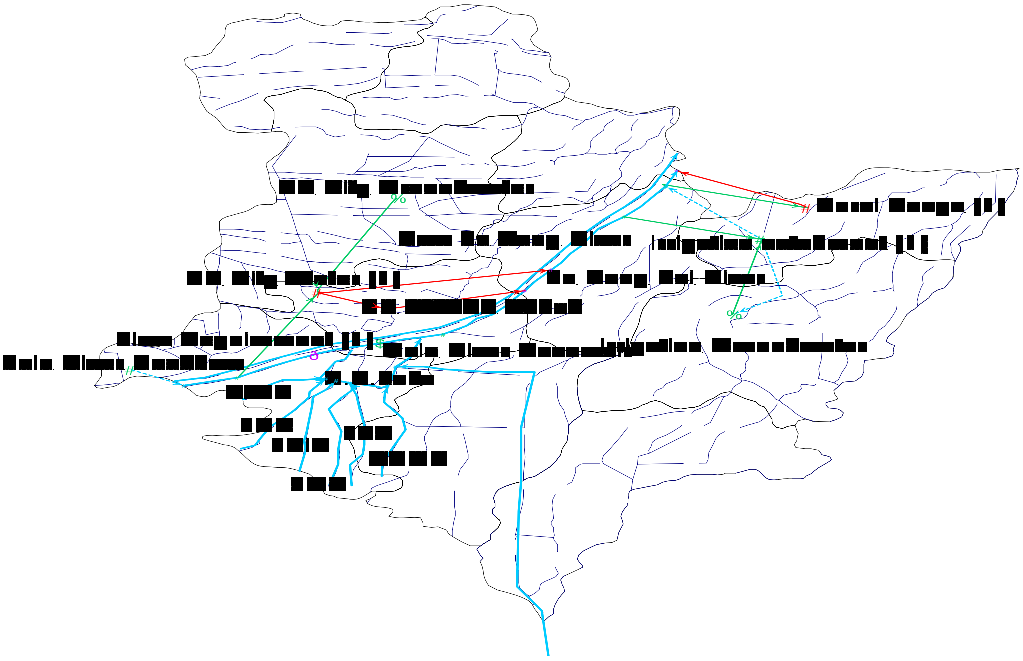


Figure 5-73: Irrigation Surface Groundwater active from 2006

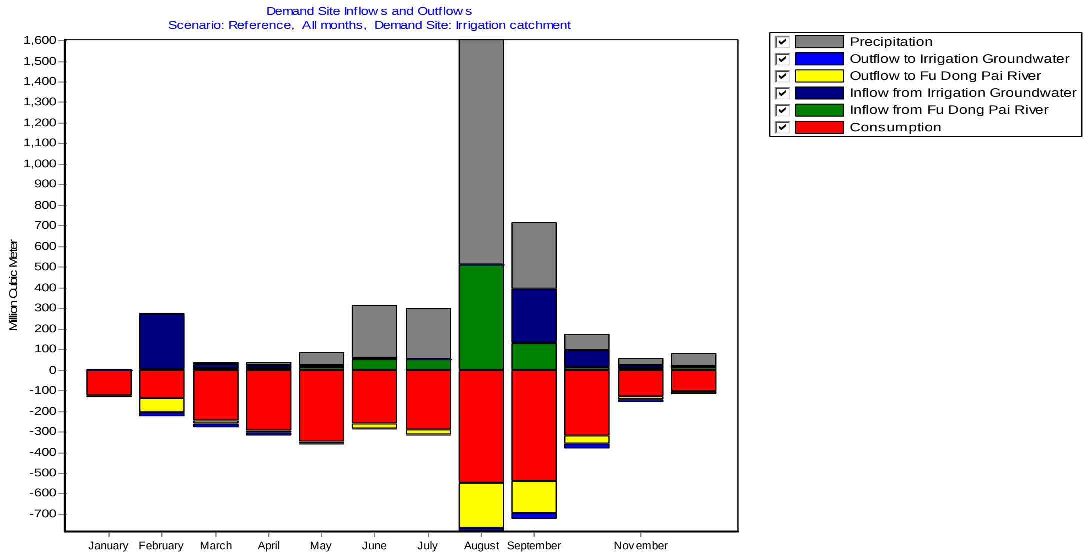



Figure 5-74: Considering the Demand Site Inflows and Outflows for Irrigation Catchment for all sources and destination for the year 2006

Note that these results include "Inflow Irrigation Groundwater" (due to the designation of Irrigation Groundwater node as a source to supply irrigation water for Irrigation Catchment and "Outflow to the Irrigation Groundwater" (due to the creation of a runoff/infiltration link between the two nodes)

Groundwater Inflow and Outflow under Supply Resource condition

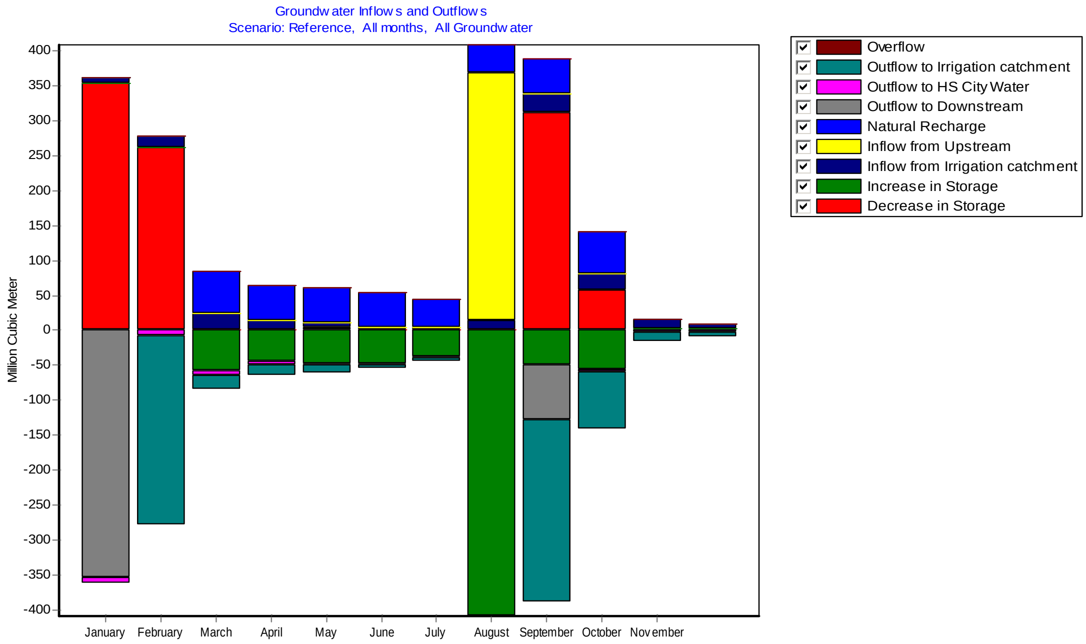



Figure 5-75: Considering Groundwater Inflows and Outflows, for the year 2006

Note that the "Inflow from Upstream" category indicates infiltration of Main River water to Irrigation Groundwater along the river reach as selected earlier, "Outflow to Downstream" represent groundwater seepage into the Main River.

Note that the natural recharge mostly in the month with greater surface water March to October, so also is the increase storage capacity of groundwater with the peak storage in the month of August, contrariwise is the decrease storage from the month of September through February with the peak in the month of January during the frost winter period. Groundwater gets most of Inflow from the upstream especially in the month of August due to High precipitation and available surface water, while little Inflow is gotten from Irrigation catchment for all months, see Figure 5-74

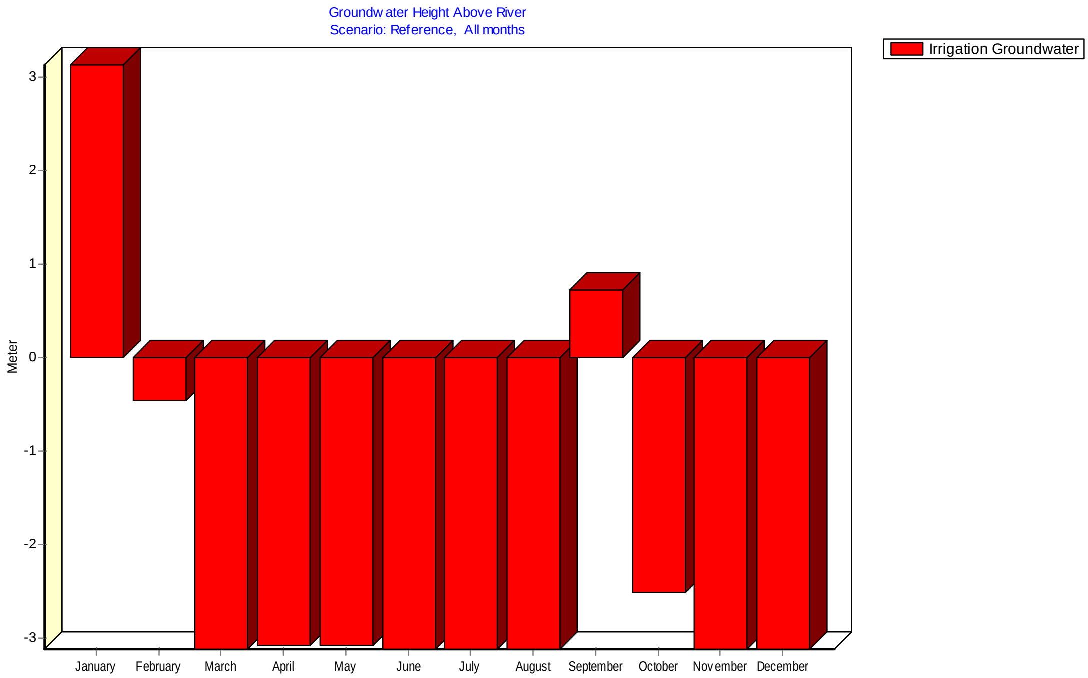



Figure 5-76: The monthly Groundwater Height above Fu Dong Pai River.

Note that, in the month where groundwater seepage to the Main River occurs. (January and September), the groundwater elevation is higher than the wetted depth of the river as designated in the chart above (i.e the difference in the elevations is positive). Likewise, when the Main River infiltration to groundwater is occurring, the elevation difference is negative. The effect of the negative value shows the danger of excess exploitation of groundwater, which if adequate care is not taken could result to serious ecological problems.

# CHAPTER SIX

# CONCLUSION AND RECOMMENDATION

This chapter deals with the conclusions and recommendation. Section 6.2 explains the conclusions that derived from different scenarios evaluated in the report, and section 6.3 presents the recommendations.

Freshwater is a critical resource in the transition to a sustainable future. As it courses through the hydrological cycle, water is the life-line production for commerce, human needs, and innumerable aquatic ecosystems. Water resources are finite, while water demands are increasing dramatically, driven by the relentless growth of human activity in recent decades.

Complex conflicts have emerged, between competing users, between stakeholders along common source of water, and between economic growth itself and environmental preservation.

Fu Dong Pai River is a vital source of fresh water for the regions economic activities that include farming, horticulture, geothermal power generation, fishing etc. From the previous analysis the lake does suffer from water shortage. Since different scenarios have been considered, conclusions are presented separately for each scenario.

## 6.1. Conclusions

Integrated Water Resource Management goes beyond the traditional description of the resource and integrating or balancing demand. The concept embodies integration across sectors, integration of use, integration of demand, integration with the environment as well as integration with the people.

Modeling demand and supply help to observe and understand a wide long-term vision of the problem. With this aspect the area, which needed to be carried out, can be identified and helped in solving the conflict of interest between the stakeholders.

To build a Demand /Supply model the more data collected, the closer the model will be to the circumstance of the catchment and the more effectively it will identify problems.

### 6.1.1 The Reference Scenario

In the defined time period, the annual water use for Irrigation was reduced for that period by using the linear interpolation. The interpolation was for the years 2003 , 2010, 2015, 2020, 2025 and 2030 (annual water consumption rate/Ha were 3000 $m^3$, 2800 $m^3$, 2650 $m^3$, 2500 $m^3$, 2300 $m^3$, 2000 $m^3$) respectively and also changes for Heng Shui City, annual water consumption per person was increased from 24 to 300 $m^3$. This was done using a linear interpolation for same period as in irrigation, (annual water consumption 24 $m^3$, 35 $m^3$, 60 $m^3$, 100 $m^3$, 200 $m^3$, 250 $m^3$ and 300$m^3$)

By running the model after the previous change, it shows that the graphs correlate by 0.89 after calibration. The mean square error for the modeled Lake Level was 0.28; while the average difference between the observed lake level and the WEAP modeled lake level was 0.03.
The two graphs are following the same trend with high correlation but they are not identical because the demand in the model has many of assumptions and linear interpolations in the modeling, which in reality are not fully accurate.
This can be improved if more historical and detailed data about the demand can be collected.
Also population consumption depends on the assumptions made by the municipal council which maybe an estimate higher than real consumption.

**The water demand in the Heng Shui City**

In studying the water demand in the area, Figure 5-8 shows that the main consumption in the City is irrigation demand.
The city water demand is also constant except when domestic variation is computed see Figure 5-8 and 5-12. Also because of the prime location of the town, it local water supply depend on other sources of water supply rather than the river itself, through a pipeline that affects the inflow to Heng Shui Lake. So the unmet demand in Figure 5-10 was expected. The average unmet demand was 1.58 million $m^3$ / month and 49.8 million $m^3$/ month for domestic water demand and irrigation water usage respectively. All month with no unmet demand were included in the calculation.
Figure 5-10 shows only one peak of unmet demand due to the fact that the farming water usage increases and so also does the lake capacity and river inflow decreases at this period. This situation is likely to deteriorate in the future due to the progression of water demand if no measures are taken to address them. The inflow of Fu Dong Pai River was assumed to be 25% of the total inflow to Heng Shui Lake, due to the fact that to date there is no specific discharge data for this river.
At present there is a river disaggregated water balance model still being calibrated. This assumption caused unmet demand for the city to be fairly constant except for the months of July to November, with it peak in the months of September when Irrigation consumes more water causing lack to Domestic water. Meanwhile this town has other sources of water resources such as ground water and rain fed small reservoirs.

**6.1.2 The Population Scenario**

Meanwhile, the average total annual consumption in Heng Shui City increases when the population increases for two different scenarios, the unmet water demand for the population growth rate of 1.12% for Domestic and Irrigation were 28.0 million $m^3$/ month and 52.0 million $m^3$/ month respectively, while for 2.0% growth rate for Domestic and Irrigation were 38.0 million $m^3$/ month and 54.06 million $m^3$/ month respectively. Averagely, 967.73 million $m^3$/ year and 1110.8 million $m^3$/ year, is needed to fulfilled completely water coverage and for any meaningful sustainable development in Heng Shui City, given the 1.12% and 2.0% population growth. See

Table 5-8 scenarios.which includes all the demand in the catchment.
Table 6-1 only summarises the different scenarios computation for ease comparison and identification, meanwhile it could be used as the final concluding table for all the model so far simulated, reference will be made with regards this table.

Table 6-1: Summarized table showing various water resources components simulated

| | Destination | Demand | Unmet Dd | % Unmet Dd | % Coverage |
|---|---|---|---|---|---|
| Reference | City | 99.1 | 19.0 | 19.17 | 80.83 |
| | Irrigation | 1369.1 | 597.9 | 43.65 | 56.35 |
| | Total | 1468.2 | 616.9 | 42.02 | 47.98 |
| 1.12% pop | City | 593.9 | 327.7 | 55.18 | 44.82 |
| Growth + | Irrigation | 1297.8 | 614.6 | 47.36 | 52.64 |
| SIIT | Total | 1891.8 | 942.3 | 49.81 | 50.19 |
| 2.0% pop | City | 754.6 | 450.0 | 60.35 | 39.65 |
| Growth + | Irrigation | 1298.0 | 631.6 | 48.66 | 51.34 |
| SIIT | Total | 2052.6 | 1081.6 | 52.69 | 47.31 |
| Water | City | --- | --- | 40.13 | 59.83 |
| Re-use | Irrigation | ---- | --- | ---- | ---- |
| 20% Water | City | --- | ---- | 40.34 | 59.66 |
| Losses | Irrigation | --- | --- | --- | --- |
| Reservior | City | 593.9 | 172.23 | 29.0 | 71.0 |
| Added In | Irrigation | 1277.8 | 372.47 | 28.7 | 71.3 |
| August | Rural | 110.2 | 11.79 | 10.7 | 89.3 |
| | Total | 2002 | 556.49 | 27.80 | 72.20 |
| Ground | City | 754.6 | 567.89 | 24.76 | 75.24 |
| water | Irrigation | 1298.0 | 464.21 | 35.76 | 64.24 |
| Inclusion | Total | 2052.5 | 1032.1 | 50.28 | 49.72 |

### 6.1.3 Efficient Irrigation and Slight Improved in Technology Scenario

Irrigation producers adopt technically efficient irrigation methods to produce higher net incomes through increased crop yields and increased efficiency in nutrient and chemical use, the result would be reduced labour costs and more efficient water use.
One definition of on-farm irrigation efficiency is the ratio of water stored and depleted in the crop root zone for crop consumption to the total water diverted from the stream for irrigation. One method to increase on-farm efficiency, defined in this way, would be to encourage producers to apply water more consistently across fields. This enables crops to maintain, keep or increase their consumptive water use from reduced stream diversions.
This scenario is looking to the effect of applying the crop requirement irrigation on the lake level.
What will be the impact on the lake level if farmers applied irrigation equal to the crop requirement on their cultivation? How will the situation be improved?
The efficient irrigation data in Table 5-6 was used in this scenario and Table 5-7 present the results of such efficient Irrigation water uses, with the Irrigation water uses reduces to 1297.8 million $m^3$ per year as against 1468.2 million $m^3$ per year

without irrigation efficiency, accounting for 13.17% reduction in water demand usage.
Running this scenario, Figure 5-22 and 5-23 for water demand and unmet water demand, shows that the river and lake level will increase by an average of (0.9 m /n month). This means that the average agricultural demand will be reduced by 48.91 million $m^3$ / month
Applying efficient irrigation leads to reduce amount of water for cultivation. When there is excess water, the water can be reserve and store for future uses. Water could be reused, see Table 5-11, the reuse scenario, showing reduction in unmet water demand by 11% of the total water usage.

By running the water year method model using the two elements (water year types and coefficient) the river and lake level, correlated to the Reference River and lake level with correlation coefficient a (0.94), and the mean square error was 0.5.
The above water year method has been developed to study the effect on the river and lake level if the climates change in the future. It does not give accurate results but can provide a prediction of the future according to the provided water year method.
The graph shows seven cycles after the very dry years during 90's and 2000's decade. They differ in their period, which varies from 4 to 8 years as shown in Figure 5-32 for the following scenario to explore the future; the assumption will be taking a water year method cycle from 1993 to 2003, which is the medium cycle. This can be a strong tool in management and planning to explore the possible future impacts of climate change on the river and lake level. WEAP also uses the water year method, which helps to explore the future under several user-defined assumptions like climate change, the amount of demand consumption and others.
Using the water year method to model and predict the future lake level shows that if the demand keeps growing with the same activity and water consumptions, the lake level will continue the same fluctuation pattern without reaching a critical point of dryness.
The middle cycle of the water year method for the period from 1993 to 2003 was repeated for the next 10 years (2013 until 2023), while lower and upper cycle were from 2003 to 2013 and 2023 to 2030 respectively.

If water pollution is a concerned, Heng Shui have a WWTP station to treat all effluent coming to the river as a result of return flow, see Figure 5-62 to 5-63,5-65a-f, 5-66 and 5-67. Note that only 20% of the return flows were added to the simulation model because the present WWTP capacity can only accomodate 80,000 $m^3$/day and as a result, the rest 80% remained untreated and return to the water stream.

### 6.1.4 Supply Scenario

Note that in modeling the reservoir, we enter a demand priority of 99 to ensure that the reservoir will only be fill if all other needs are fulfilled, including downstream demand. The chart below shows the effect of increase reservoir storage. The storage capacity were increase to about 846.5 million $m^3$ accounted to over 270% of the

previous water supply, and we can conclude that, with this present storage, water sustainability could be achieved to some fair degree of acceptance and economy development. Net evaporation was computed to account for both rainfall and evaporation.
Groundwater resource was also taken into consideration especially relating to City water supply, this Groundwater supply though increase water availability but insufficient in fulfilling the overall city water consumption. This anticipated unmet water demand can only be supplemented from other water bodies, through water importation, as though the annual precipitation, surface water, water recycle were far from insufficient, the total water demand for the period of simulation when efficient irrigation practice were implemented was 77.997 billion $m^3$ for the simulation period 1993-2030, while the total water supply (including Reservoir, Reuse, Precipitation, Groundwater and the Main River Fu Dong Pai) was 39.22 billion $m^3$ accounting for only 50.28%, the remaining 38.777 billion $m^3$ accounting for 49.72% is the big question to sustainability in Heng Shui Municipality.

Although various graphical illustration where also presented to show the effect of building a buffer in the reservoir, the flow requirement, streamflow and Modeling Catchment for Rainfall Runoff, Soil Moisture and Groundwater Interaction on the Lake and River flow and water availability.

## 6.2 Recommendations

Based on the results and analysis of different parameters that can affect the River, Lake Level and the catchment, the following points are recommended:

**Building reused water reservoir**
Mostly the extra water, carrying chemicals, goes back to lake as return flow.
The irrigated farmers may try to reduce the water consumption from the lake through two new methods: Building a reservoir to collect the extra water from the applied irrigation. This will reduce the water consumption through reuse, and reduce the fertilizers. Fifty percent of the collected water will be reused, which will reduce the over irrigation.
Using the hydroponics soils for mechanized irrigation, because its increases the productivity up to 100% per unit area, and extends the life of the mother plant. At the same time this will also save the water through reuse by 50 %.
From the above it can be concluded that by applying the reuse of 50% in the mechanized irrigation, either by using the hydroponics soils or by building a reservoir, the lake level will increase by 250 million $m^3$ during year 2030.

**Water Pricing**
The installation of water metering for every abstraction point, is assumed to increase population awareness of water use. In fact, water pricing in the irrigation schema is important because big farms will apply the best irrigation practices to save water and

to increase productivity of their farms thus to saving money spent on water.
Vegetable and fodder farms use poor irrigation technology. Therefore they will be forced by the water pricing and metering system to revaluate their irrigation practices. The installation of water meters frequently is in line with public concerns for better use of water resources and the request for a better management of the water environment. Reliable water metering is a stringent requirement for the implementation of effective water charges. Water Pricing is an important issue and it should be implemented according to the benefit or the economic return for which it is used.
Usually applying such ideas will not be embraced by every one; never the less this should be carried out to avoid irrigated farmers from using water irrationally, to also extend the water pricing to include activity other than non-agricutural use as domestic and industries.

**Expansion of the model to include the New Fu Yang River**: Climate change will impact the hydrology and water management decisions in the New Fu Yang River and other small water tributaries. These have implications for Fu Dong Pai River inflows and exports that need to be considered. Hence, there is need to expand the use of New Fu Yang River to reduce the over exploitation of groundwater resource.

**Water Importation from other source:** From the model above, we can see that, the water resource supply to cover the excess need is beyond the water capacity Heng Shui Municipality can handle, there is no need concealing the fact that, water importation is eminent and a matter of urgency and necessity, here we are talking about 1.1 billion $m^3$ of water annually.

**Increasing Water Reservoir capacity and building new ones:** Increasing water reservoir is necessary as it could be used to store water during excess water year, though so far excess water capacity had not occur, but are not ruling out the possibility especially when after the completion of the South to North water diversion project, which will increase water supply and availability and also the very wet years period could pull excess water.

**Increased the Waste Water Treatment Plant Capacity:** The effectiveness of the WWTP could not be over emphasize, with the rapid economy growth and irrigation activities, there are strong possibilities of high pollution from use of chemicals, pesticide as shown from the model. Presently only 20% of the effluent is pass to the WWTP for treatment while 80% flow back to the river untreated, this is not a good practice, since part of this water are again use for rural consumption and could be harmful to the health. Provision of this WWTP will help in keeping High water quality and increased water availability too.

**Information Dissemination:** There is need to develop networks to share information and experiences on water resources management Information Systems (collect, use, and exchange information and experiences on water resources)

**Development Professional Manpower:** To develop a new cadre of professionals with an integrated vision of water resources planning and management who, in addition to their specific training, will broaden their post-graduate level knowledge of social, environmental, economic and legal issues in order to acquire the appropriate training to implement integrated management for better sustainable development.
**Model Extension:** Include in the modeling software the connection between the ground water and Heng Shui Lake an important part of the catchment. We can also explore other factors, such as the pollution generated by agriculture, that may strengthen the models and thus planning and management capacities.

# REFERENCES


1. **Abu-Taleb, Maher F. 2000**. Impacts of Global Climate Change Scenarios on Water Supply and Demand in Jordan. *Water International* 25: 457-463.
2. **Adler, R. W. 2002**. Fresh Water. In *Stumbling Toward Sustainability*, edited by J. C. Dernbach. Washington, DC: The Environmental Law Institute.
3. **Bartlett, A. A. 1999.** Colorado's Population Problem. *Population Press* 5(6): 8-9**.**
4. **Birnie, P. W. and A. E. Boyle. 2002.** *International Law and the Environment.* 2d ed. Oxford, UK: Oxford Univ. Press.
5. **Boyle, Alan and David Freestone., eds. 1999.** *International Law and Sustainable Development: Past Achievements and Future Challenges.* Oxford, UK: Oxford University Press.
6. **Brown Weiss, Edith. 1999**. Understanding Compliance with International Environmental Agreements: The Baker's Dozen Myths. *University of Richmond Law Review* 32:1555-1589. "Brundtland Report." 1987. *World Commission on Environment and Development: Our Common Future.* New York: United Nations.
7. **Chang, Gordon G.,** "The Problem with Water, Part 1". China Brief. Volume II, Issue 19, 26 Sept. 2002.
8. **Dellapenna, Joseph W. 1997.** Population and Water in the Middle East: The Challenge and Opportunity for Law. *International Journal of the Environment and Pollution* 7:72-110.
9. **Diaz, Leticia M. and Barry Hart Dubner. 2001.** The Necessity of Preventing Unilateral Responses to Water Scarcity—The Next Major Threat against Mankind This Century. *Cardozo Journal of International and Comparative Law* 9: 1-40.
10. **Dupuy et al 1991**. NETMATE: A Network Management Environment. Computer Science Department, Columbia University, New York, 10027.
11. **Esty, Daniel C. 1998.** Sustainable Development and Environmental Federalism. *Widener Symposium Law Journal* 3: 213-228.
12. **Flint, R. W. 2003.** Sustainable Development: What does sustainability mean to the individual in the conduct of their life and business. In *Handbook of Development Policy Strategies*, edited by G. M. Mudacumura. New York: Marcel Dekker, Inc.
13. **Flint, R. W. and M. J. E. Danner. 2001.** The nexus of sustainability and social equity. *International Journal of Economic Development* 3(2). [Online]. Available at http://spaef.com/IJEC_PUB/v3n2.html.
14. **Flint, R. W. and W. L. Houser. 2001.** *Living a Sustainable Lifestyle for Our Children's Children*. Campbell, CA: IUniverse.
15. **Flint, R. W., F. C. Frick, A. Duffy, J. Brittingham, K. Stephens, P. Graham, and C. 2002.** Strategic Orientation for Sustainable Regional Development in The Characteristics of Sustainable Destination Resort Communities Background report. Campbell, CA: IUniverse
16. **Flora, Cornelia Butler. 2002.** Social Capital is Critical, Even in State of High Alert. *Rural Development News* 25(3). [Online]. Available from http://www.ag.iastate.edu/centers/rdev/newsletter/Vol25No3-2001/socialcap.html [Accessed 26 October 2003].

**17.** **Flora, Cornelia Butler. 2000.** Measuring the Social Dimensions of Managing Natural Resources. In *Human Dimensions of Natural Resource Management: Emerging Issues and Practical Applications*, edited by D. C. Fulton, K. C. Nelson, D. H. Anderson, and D. W. Lime. St. Paul, MN: University of Minnesota and USGS-Biological Resources Division, Minnesota Cooperative Fish and Wildlife Research Unit and Cooperative Park Studies Program. [Online]. Available at http://www.cnr.umn.edu/CPSP/Research/ HumanDimensions.pdf [Accessed 10 October 2003].

**18.** **Fuentes, Ximena. 1998.** Sustainable Development and the Equitable Utilization of International Watercourses. *British Yearbook of International Law* 69:119-200.

**19.** **Gasteyer, Stephen P., Cornelia B. Flora, Edith Fernandez-Baca, Damayanti Banerji, Stacy Bastian, and Silvia Aleman. 2002.** Community Participation for Conservation and Development of Natural Resources: A Summary of Literature and Report of Research Findings. *Delta Development Journal* 1(1).

**20.** **GHZB1-1999, Environmental quality standard for surface water. 20 Feb. 2003** <http://www.zhb.gov.cn/english/standard/GHZB1-1999.doc>.

**21.** **Gleick, Peter H. 1993.** Water Scarcity and Conflict. In *The Environment and Security: What Are the Linkages?* Canberra, Australia: Australian National University (Canberra Papers on Strategy and Defence, no. 125).

**22.** **Gleick, Peter H. 2002.** *The World's Water 2000-2001: The Biennial Report on Freshwater Resources.* Washington, DC: Island Press.

**23.** **Gleick, Peter H *et al.* 1995**. *California Water 2020: A Sustainable Vision.* Oakland, CA: Pacific Institute for Studies in Development, Environment, and Security.

**24.** **Glennon, Robert J. 1991.** "Because That's Where the Water Is": Retiring Current Water Uses to Achieve the Safe-Yield Objective of the Arizona Groundwater Management Act. *Arizona Law Review* 33:89-114.

**25.** **Hall, K. 2003.** Tackling World's Water Crisis Could Cost Up To US $100 Billion a Year. In Environmental News Network [Online]. Available at http://www.enn.com/news/2003-03-06/s_3213.asp).

**26.** **Hallding 1993.** Modeling Water Resources Management in lake Naivasha. U.S.A.

**27.** **Harry X. Zhang and Qishun Zhang 2003** Integrated Watershed and Ecosystem Management for Eco-City Development: An International Perspective

**28.** **Hufschmidt et al 1993.** *State of the art in adaptive user interfaces*'. In: M. Schneider-Hufschmidt, T. Kühme and U. Malinowski (eds.): Adaptive user interfaces: Principles and practice. Amsterdam: North-Holland, pp. 1348. Journal of Computing and Informatics 18, 357-366.

**29.** **International Court of Justice.** *The Gabcíkovo-Nagymoros Case (Hungary v. Slovakia),* 1997 ICJ No. 92, par. 140, reprinted in *International Legal Materials* 37:162-242 (1998).

**30.** **Jerry a. nathanson 2003.** Basic Environmental Technology, water supply management, and pollution. Pearson education Inc., publishing as prentice Hall. 4th edition.

**31.** **Korhonen, Iris M. 1996.** Riverine Ecosystems in International Law. *Natural Resources Journal* 36: 481-519.

32. **Krantz et al 1997.** Hydrogeologic Setting and Ground Water Flow Beneath a Section of Indian River Bay, Delaware 1Department of Earth, Ecological and Environmental Sciences, University of Toledo, Toledo, OH 43606.

33. **Kukk, Christopher L. and David A. Deese. 1996.** At the Water's Edge: Regional Conflict and Cooperation over Fresh Water *UCLA Journal of International Law and Foreign Affairs* 1:21-64. "Lake Victoria Fisheries Convention." 1994. Convention for the Establishment of the Lake Victoria Fisheries Organization, Kenya-Tanzania-Uganda, *signed* 30 June 1994, reprinted in Christy, No. 19, at 122-141.

34. **La Rivière, Maurtis. 1989.** Threats to the World's Water. *Scientific American* 261(3): 80-90.

35. **Lester R Brown and Brian Halwall 2003.** Who Is To Rear China, Not To Be Misled by the 'Food Crisis' Theory. www.china-review.com/english/eng-22.htm

36. **Lomborg, B. 2001.** *The Skeptical Environmentalist: Measuring the real state of the world.* Boston: Cambridge University Press.

37. **McCaffrey, Stephen C. 2000.** Water, Water Everywhere, but Too Few Drops to Drink: The Coming Fresh Water Crisis and International Environmental Law. *Denver Journal of International and Comparative Law and Policy* 28: 325-337.

38. **Miersch, J. D., J. C. Bell, and J. L. Anderson. 2001.** Out of the Creek: A Wastewater Decision Case. *Journal of Natural Resources and Life Science Education* 30: 93-96.

39. **Morse and Bazzaz (1994).** Environmental growth chambers, 18 °C. 3% survival and growth. Ecology 76: 1587-1602

40. **Nachmani 1994.** "'They Have Oil, We Have Water; Let Them Drink Their Oil': A Study of the Politics of Water in the Middle East," in Hellenic Foundation for Defense and Foreign , 35, The Jerusalem Center for Public Affairs**...**

41. **Ostrom, Elinor. 1996.** *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge, UK: Cambridge University Press.

42. **Postel, Sandra. 1992.** *Last Oasis: Facing Water Scarcity.* New York: W.W. Norton..

43. **Postel 1999.** Earth Trend: Feature- will there be enough water. *Pilot Analysis of Global Ecosystems: Freshwater Systems*

44. **Robert, K.H. 1991.** Educating a Nation: The Natural Step. In *Context* 28, In Context Institute [Online]. Available at http://www.context.org/ICLIB/IC28/Robert.htm.

45. **Roseland, Mark. 1996.** *Toward Sustainable Communities: Resources for Citizens and their Governments.* Gabriola Island, Canada: New Society Publishers.

46. **Ruhl et al 1999.** The Southern Inland and Coastal System Project of the USGS South Florida Ecosystem**.** Marine Biology Research Division Scripps Institution of Oceanography 9500 Gilman Dr. La Jolla, CA 92093-0202

47. **Ryan, J.C. 1997.** *Stuff - The Secret Lives of Everyday Things.* Seattle, WA: Northwest Environmental Watch.

48. **Sandia National Laboratories. 2003.** Water Safety, Security, and Sustainability. Albuquerque: Sandia National Laboratories. [Online]. Available at http://www.sandia.gov/water/FactSheets/WFS_RiskAs.pdf.

49. **Shucheng Wang**. Enforce the Water Law seriously; facilitate the development of water conservancy. *Water Policy and Water Resources. 2002(5) , 14~15*

50. **Shucheng Wang**. Sustain the ecosystem well in facilitating sustainable development of

socioeconomic by means of sustainable water resources utilization. *Water Policy and Water Resources. 2002(5)，* 4~6l >.

***51.*** **Sustainable Utilization of Water Resource in China. 13 Feb. 2003** <http://www.lanl.gov/chinawater/documents/zhangchunyuan.pdf >.

***52.*** **Tietenberg, T. 2003.** *Environmental and Natural Resource Economics, 6th Ed.* Boston: Addison Wesley.

***53.*** **UNESCO, 2003.** Water for People, Water for Life: The World Water Development Report. World Water Assessment Programme, United Nations, NY. [On-line]. Available at http://ens-news.com/ens/mar2003/2003-03-05-02.asp).

***54.*** **Vorosmarty, C. J., P. Green, J. Salisbury, and R. B. Lammers. 2000.** Global water resources: vulnerability from climate change and population growth. *Science* 289: 284-287.

***55.*** **Wei, Xue. "Zhongguo Jingji Fazhanzhong de shuiziyuan Wenti Fenxi"** ("Water Resources and Economic development in China"). China Economic Studies. Vol. 29 no. 1, January-February 1996: 76-95.

***56.*** **Wolf, Aaron. 1998.** Conflict and Cooperation along International Waterways. *Water Policy* 1:251-263.

***57.*** **Zhang, Q., and Zhang, X., 1995.** Water Issues and Sustainable Social Development in China, *Water International* 20: 122-128

***58.*** **Zhang, Q., and Zhang, X., 2001.** Five Current Important Water Issues for Sustainable Development in China, *Water International* 26: 231-238

***59.*** **Zhang, H. X. and Zhang, Q., 2002.** Water Issues and Sustainable Water Resources Development in China, *WEFTEC 2002*, Sep. 28 – Oct. 2, Chicago, Illinois, USA

***60.*** **Zhang, Zhiping,** "Debates on South-to-North Water diversion Project", Beijing Review, 08/28/2000, Vol. 43 Issue 35, p26-28

## INDEX FOR FAO RUNOFF

Units and definitions for all variables in FAO Runoff Equation are:

**Area [HA]** - Area of land cover
**Precip [MM]** - Precipitation
**PrecipEffective [%]** - Percentage of precipitation that can be used for evapotranspiration
**PrecipAvailableForET [MCM]** - Precipitation available for evapotranspiration
**Kc** [-] - FAO crop coefficient
**ETreference [MM]** - Reference crop evapotranspiration
**ETpotential [MCM]** - Potential crop evapotranspiration
**PrecipShortfall [MCM]** - Evapotranspiration deficit if only precipitation is considered
**IrrFrac [%]** - Percentage of supplied water available for ET (i.e. irrigation efficiency)
**SupplyRequirement [MCM]** - Crop irrigation requirement
**Supply [MCM]** - Amount supplied to irrigation (calculated by WEAP allocation)
**EF [-]** - Fraction of potential evapotranspiration satisfied
**YieldResponseFactor [-]** - Factor that defines how the yield changes when the

ETactual is less than the ETpotential.
**PotentialYield [KG/HA]** - The maximum potential yield given optimal supplies of water
**HU**- Hydro Unit
**LC**- Land Cover
**I**- Irrigation
**NI**- Non Irrigation.
**ActualYield [KG/HA]** - The actual yield given the available evapotranspiration
**Runoff [MCM]** - Runoff from a land cover.
**RunoffToGW [MCM]** - Runoff to groundwater supplies.
**RunoffToSurfaceWater [MCM]** - Runoff to surface water supplies.

## INDEX FOR DEMAND SITE

**DS**-Demand Site
**TP**-treatment Plant
**GW**- Ground water

## ABBREVIATION FOR LAKE NAMES USED IN THE MODEL

**RWD**- Rong Wang Di
**JNC**- Ji Nan Chu
**HS Lake**- Heng Shui Lake
**JNiC**- Ji Ni Chu
**JMC**- Ji Mao Chu
**JZC**- Ji Zao Chu
**YHGD**- Yan He Gu Dao
**WQC**- Wei Qian Chu

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