US Army Corps of Engineers®

Kandahar City Water Supply Master Plan
Kandahar Province, Afghanistan

Commander's Emergency Response Program

Prepared for

International Security Assistance Force, Regional Command South

International Security Assistance Force Regional Command South	Government of the Islamic Republic of Afghanistan

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EXECUTIVE SUMMARY

Kandahar City, Afghanistan suffers from operational deficiencies in its municipal water supply system, poor water quality due to contamination, and increased competition for a limited water supply. Because of these factors, the city's population lacks access to basic levels of safe drinking water as set by the World Health Organization (20 liters per person per day) to ensure good health. In order to achieve a basic level of access and improve water quality, upgrades to Kandahar City's municipal water supply system are necessary.

The objectives for this project were developed by the Project Delivery Team (PDT) with the intent of meeting the goal to provide access to safe drinking water to residents of Kandahar City in a timely manner. Objectives were initially developed at the kick-off meeting for this project and refined throughout as the planning process progressed. Initially, the project was primarily focused on assessing groundwater development. When it became apparent the regional aquifers would be unable to meet long-term demand of the population, the project began evaluating surface water from the Arghandab River, specifically from Dahla Dam. Objectives were also developed with input that was received from local water authorities, Ministry of Energy and Water, and other local organizations. The objectives of this project are:

1. Provide a plan to meet near-term basic access needs of 20 lpcd and long-term optimum access needs of 120 lpcd for the population of Kandahar City. (Objective 1 will be accomplished by assessing regional surface water resource conditions and conditions in regional deep and shallow aquifers.)
2. Near-term water supply sources should focus on meeting minimum water quality requirements using less resource intensive treatment methods such as disinfection, in order to enable quicker and more practical water access to the population. (Objective 2 will be accomplished by assessing water quality of surface water and the deep and shallow aquifers.)
3. Determine the suitability and feasibility of a Ranney well system relative to traditional vertical wells.
4. Identify components needed to connect the proposed currently under construction three deep aquifer groundwater wells to the existing distribution system.
5. Identify the overall recommended treatment, storage, and transmission components required to supply Kandahar City with a reliable water supply system.
6. Develop an overall conceptual design and approach for distribution phasing, cost estimates, and guidelines for operation and maintenance by Afghans.
7. Produce documents suitable for donors based on the objectives listed above.

One major issue impacting Kandahar City's basic water access level is the operational deficiency in the municipal water system. Out of 15 municipal wells in the city, only nine were reported as operational, and treatment and/or disinfection is not provided. The basic existing distribution system, which serves only 20% of the city, was constructed in the 1970's and, although the system has been partially expanded by the World Bank, United Nations-HABITAT, and the International Committee for the Red Cross in recent years, decades of conflict have stifled any substantial efforts to improve, maintain, and expand the system to benefit the majority of the population.

In addition to a partially functioning water supply system, the water supply, which originates primarily from a relatively shallow aquifer in Kandahar City (city aquifer), is characterized by high salinity and biological and chemical contaminants. Since historical water quality data for Kandahar City are limited, it is suspected that this contamination is the result of surface infiltration of wastewater due to a lack of a wastewater collection system other than open ditches. This lack of a proper wastewater collection and treatment system also contributes directly to poor health conditions in the city as runoff continuously discharges into the Loy Walla Canal that divides the city in north and south.

Drought, population increases, and environmental/economic needs have increased competition for scarce water resources in the region. Effects from the 2001 drought are still rampant. Reportedly, many displaced persons from rural areas have come to live on the periphery of Kandahar City, usually in areas with limited access to water. This has caused a rapid population increase in and around Kandahar City in the last five years. While the situation for agriculture in Kandahar Province has improved since the drought, there remains a lack of equitable and shared access to water between agricultural users, formal residents, and informal residents (i.e., internally displaced persons and Kuchis), which enhances tension and social instability in the community and impacts on the water available for human consumption.

As part of the Kandahar City Water Supply Master Plan Project, several water sources were considered during a detailed assessment of regional groundwater and surface water conditions. To accomplish the evaluation of groundwater resources, a hydrogeological model was developed to spatially relate geology, hydrogeology, recharge areas, and water levels to discharge areas. Four aquifers in the region were identified and modeled to estimate changes to groundwater conditions based on an array of potential groundwater production rates as depicted in Figure ES-1. Results of the modeling indicate that the deep aquifer east of Kandahar City (Zone 1) is a sustainable source of water. Combined with the aquifer beneath the city (Zone 4) both can potentially meet near-term basic access needs of 20 liters per person per day.

Modeling results indicate that the Zone 1 aquifer could sustainably yield a maximum withdrawal rate of 13,700 m^3/day, Zone 2 showed the potential to sustain a withdrawal rate of 9,000 m^3/day, Zone 3 has shown no potential to meet the long-term supply needs of the city, and the Zone 4 aquifer could sustainably yield a maximum withdrawal rate of 10,000 m^3/day in order to meet the 20 liters per person per day minimum demand. Results of surface water assessments indicate that the Dahla Dam reservoir has the potential to meet the recommended long-term demand of 120 liters per person per day based on a projected population of 1.2 million by 2030. The required daily amount of water to meet this demand is approximately 142,000 m^3/day.

Four alternatives were considered to provide access to safe drinking water to all of the population in Kandahar City, specifically (1) take no action (baseline), (2) supply Kandahar City with 100% groundwater, (3) supply Kandahar City with a combination of groundwater and surface water, and (4) supply Kandahar City with groundwater first then transition to surface water only with groundwater being a backup source. Based on outcomes of Alternative 1 (No Action), the project objectives are not met. Based on stated outcomes of Alternative 2 (Supply Kandahar City with 100% groundwater), the project objectives are not met. Based on stated outcomes of Alternatives 3 and 4, both of these alternatives meet the project objectives. Either one of these alternatives is acceptable based on their ability to meet both near-term basic access needs and long-term optimum access needs. The major difference between these alternatives is that Alternative 4 discontinues the use of groundwater once a supply from Dahla Dam comes on-line, and Alternative 3 does not.

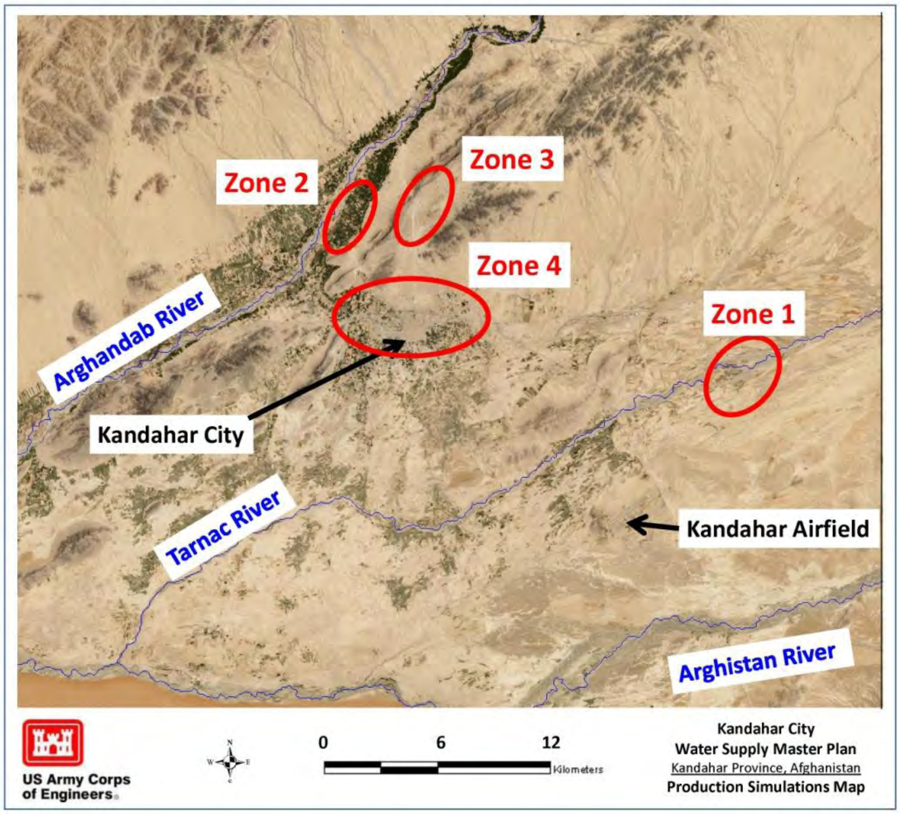


Figure ES-1. Potential Locations of Regional Aquifers

The costs of implementation for the project include all costs associated with the project, such as development costs, real estate costs, and operation and maintenance, and monitoring costs. For this study estimation of costs was performed at the 10 percent level due to lack of information available to the USACE PDT. For example, real estate costs were not estimated and operation and maintenance costs are difficult to estimate. The stream of costs associated with the project occurs at various points in time. Therefore, all costs were present-valued to the beginning of the period of analysis, and amortized at the FY11 federal discount rate of 4.125 percent over the 50-year period of analysis, to develop equivalent average annual costs.

The table below shows the annualized water supply costs for the project alternatives assessed. Based on the analysis shown the least-cost alternative is Alternative 4, supplying groundwater first, then surface water with groundwater being a backup source. The average annual cost of Alternative 4 is approximately $89,531,596, however approximately $76,000,000 of this cost each year is associated with the distribution network construction costs. Costs of this alternative neither account for future improvements to the storage capacity of the reservoir nor lost income in the farming sector due to reallocation of storage. If applicable, inclusion of these costs would also increase the average annual cost of both Alternatives 3 and 4. Since project objectives are not met without a supply from the Dahla Dam reservoir Alternative 4 would still be the preferred alternative, and is therefore the recommended plan.

Table ES-1. Annualized Costs by Alternative

	Annualized cost (in thousands of dollars)	Projected average day water production (m^3/day) - Time Period			
		2012 - 2015	2016 - 2020	2021 - 2025	2026 - 2030
Alternative 2 (100% GW)*	$ 103,503,485	32,700	32,700	32,700	32,700
Alternative 3 (GW and SW)	$ 94,534,389	23,700	109,925	142,000	142,000
Alternative 4 (GW first, then SW as backup)	$ 89,531,596	23,700	106,500	142,000	142,000

*Alternative 2 does not meet the long-term demand by a factor of approximately 4.3. While the ability to increase groundwater development does not exist, based on the cost of the development occurring in it would take an additional $73,000,000 of average annual costs to meet the demand using groundwater for a total average annual cost of $176,503,485 to meet long-term demand.

Alternative 4 proved to be the most adequate solution that can meet the planned demand in the short and long term. Alternative 4 specifically recommends providing treated groundwater from Zone 1 and Zone 4 to meet near-term basic access needs and treated surface water from Dahla Dam to provide long-term optimum access needs to the population of Kandahar City. Zone 1 is recommended under this alternative because the deep aquifer at this location is less susceptible to drought and seasonal climate variation, and is thought to be the most dependable source. This aquifer will serve as a backup source to the surface water supply and also meets the basic access level demand for the existing population of 20 lpcd. Zone 4 is recommended because it already contains existing infrastructure and is the quickest option for supplying the population with water. However, because of operation and maintenance costs, water quality concerns, and the potential impacts of drawdown in the city aquifer this supply will be abandoned as a municipal source of water once the reservoir supply is made available. The following is a list of outcomes of the recommended plan.

Near-term outcomes (2012 – 2015)*:

- Approximately 75% of the city served about 40 lpcd.
- Approximately 75% of the population is within either 150 m or 400 m of a watering point.
- Optimal water quality from Zone 1 but still questionable coming from Zone 4.

Mid-term outcomes (2016 – 2020):

- Approximately 100% of the city (881,000 people in year 2020) served about 120 lpcd.
- Approximately 100% of the population is within 150 m of a watering point or has a household connection.
- Optimal water quality from Dahla Dam and Zone 1 (backup source).

Long-term outcomes (beyond 2020):

- Approximately 100% of the city (1,200,000 people in year 2030) served about 120 lpcd.
- Approximately 100% of the population is within 150 m of a watering point or has a household connection.
- Optimal water quality from Dahla Dam and Zone 1 (backup source).

*It is assumed that the existing system rehabilitation and expansion, and strategies supply of water using tanker trucks can reach 75% of the population in the near-term.

The recommended plan proposes to expand service levels to the city using a phased-approach beginning with rehabilitating the existing distribution network to provide treated groundwater to the community. The benefit of using groundwater initially is that wells can be quickly drilled and water can be made available to residents via tanker truck while distribution network infrastructure is being constructed. To satisfy the immediate needs, a variation of the public standpost has been included with this Master Plan. This variation allows for a temporary on-site storage tank to be installed and serviced by water trucks. As construction progresses, the on-site tank would be removed, and the standpost would be directly connected to the distribution system. Once the distribution system is connected to the supply, the public standposts can be connected to the zone hub tanks. A typical hub zone layout is shown in Figure ES-2.

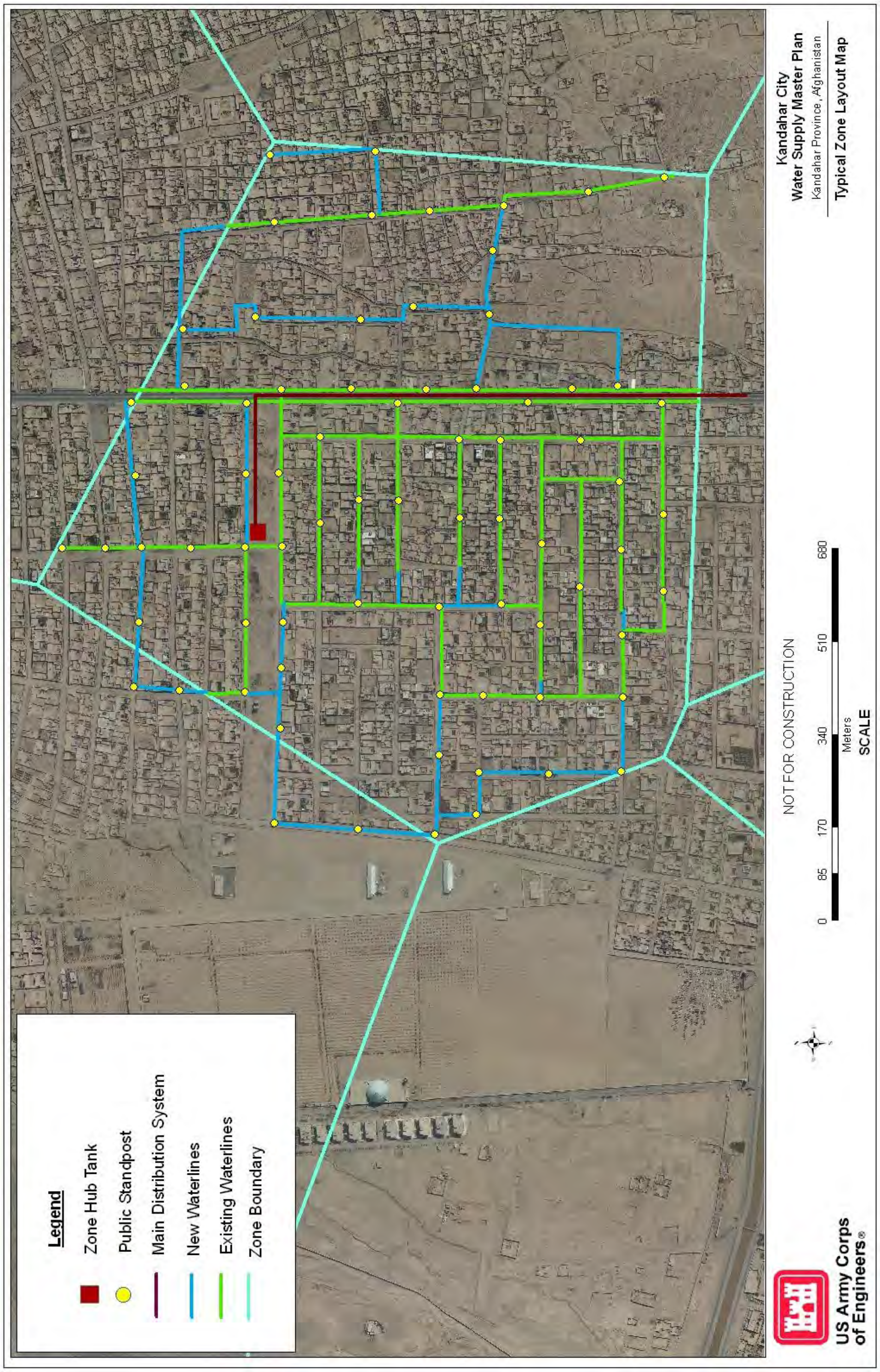


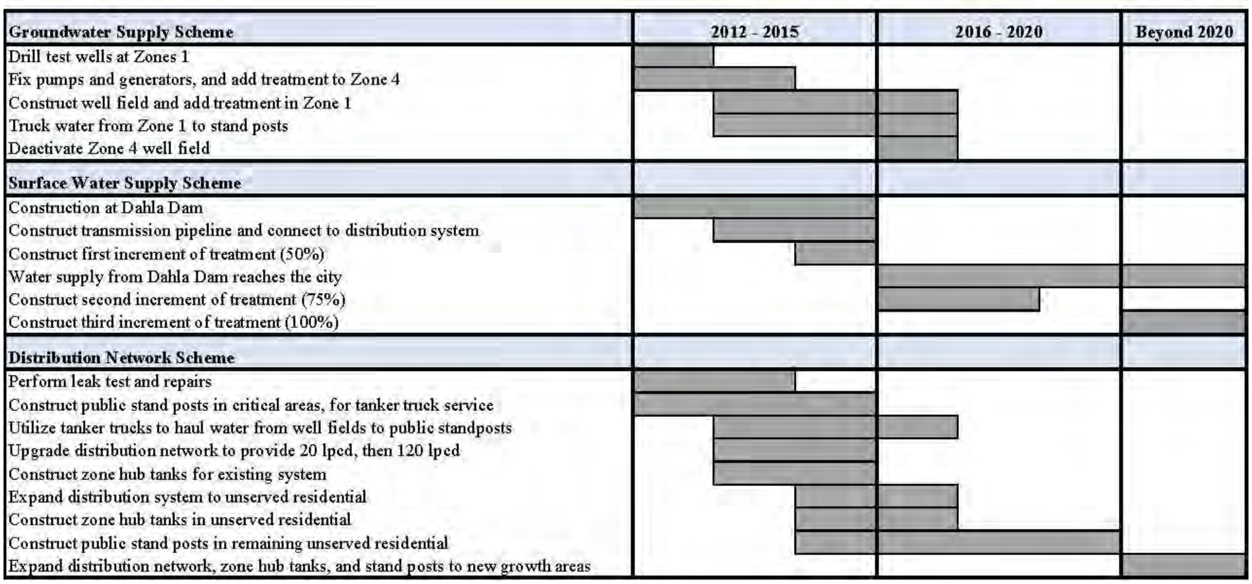
Figure ES-2. Typical Hub Zone Layout

After stabilizing the existing distribution system, expansion to meet a demand of 120 liters per person per day will be necessary. The proposed expansion includes upgrades to the system in preparation for connection to the Dahla Dam water supply. Once treated surface water from Dahla Dam becomes available, the remaining zone hub tanks and standposts can be constructed in the existing residential areas not yet served and connected to the distribution system.

The benefit of this proposed phased-approach is that the distribution system can be incrementally upgraded to provide water as pipes in each phase are upgraded. By focusing on smaller portions of the city, water can be supplied in phases more quickly. Figure ES-3 (see page ES-7) depicts the proposed expansion of the municipal water system for Kandahar City to meet a demand of 120 liters per person per day with surface water supply.

Figure ES-4 below outlines the timeline associated with the Kandahar City Water Supply Project construction phasing. Assuming that the proposed plan starts implementation in 2012, groundwater is likely to be the sole source of water until around 2016, at which point surface water becomes the sole source with groundwater as an emergency and back-up source.

Figure ES-4. Construction Phasing



Estimated costs for ground water supply, surface water supply, and distribution network and storage were calculated based on existing information available from projects currently under execution in Afghanistan. Those costs are detailed in the body of the report.

Providing access to safe drinking water to the population of Kandahar City is a paramount effort that needs many resources and coordination among agencies, however, it is technically feasible within the timeframe proposed. In order to successfully implement the proposed plan, the Afghanistan Urban Water Supply and Sewerage Corporation and Government of the Islamic Republic of Afghanistan will need to start conversations with donor countries and agencies on the proposed plan in the very near future.

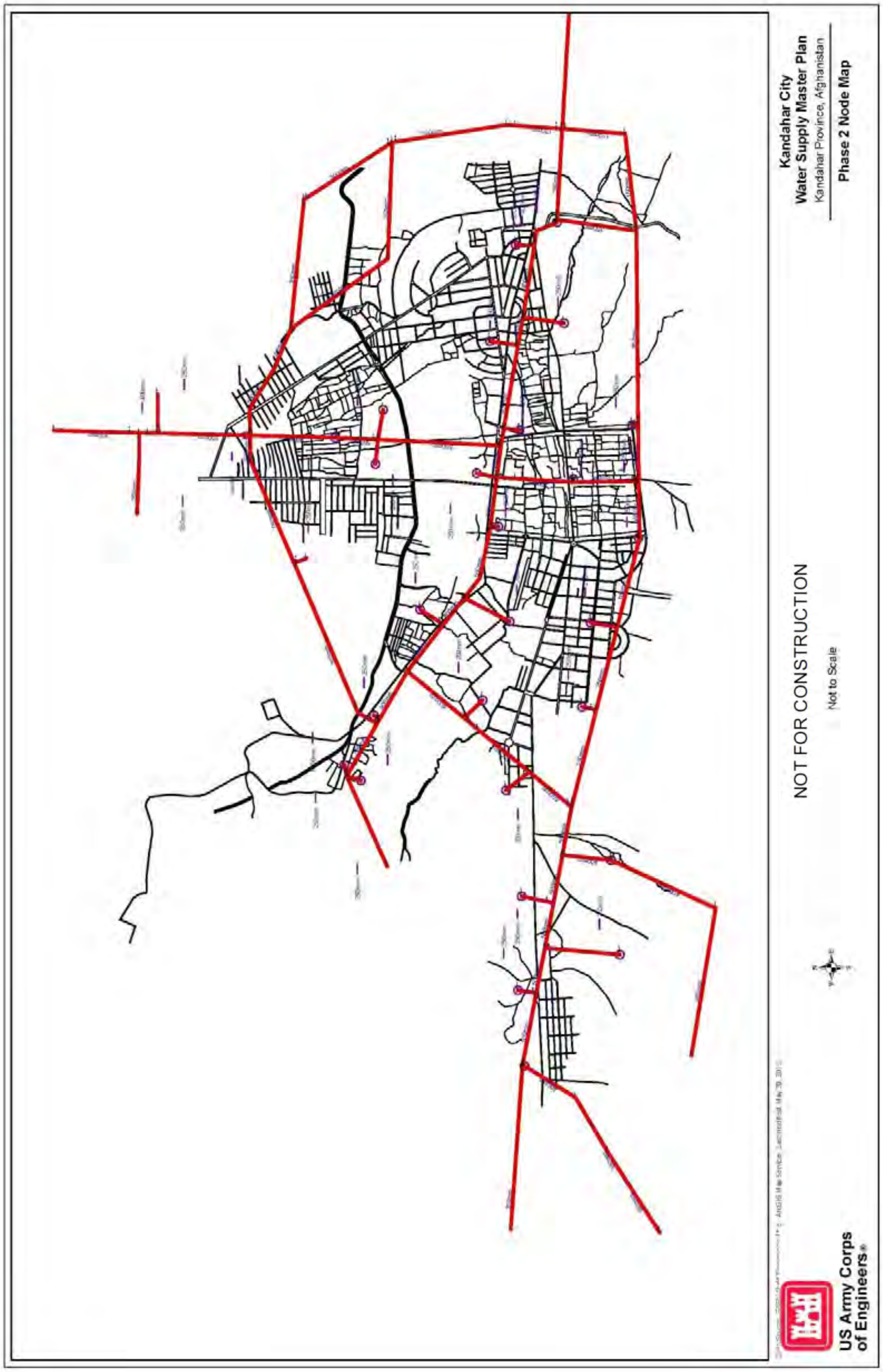


Figure ES-3. Phase 2 Distribution Network Map

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AED-S	Afghanistan Engineer District - South
AICC	Afghan International Chamber of Commerce
AIP	Arghandab Irrigation Project
ANDS	Afghanistan National Development Strategy
AUWSSC	Afghanistan Urban Water Supply and Sewerage Corporation
CAWSS	Central Authority for Water Supply and Sewerage
CERP	Commander's Emergency Response Program
CIDA	Canadian International Development Agency
CONUS	Continental United States
CPAU	Cooperation for Peace and Unity
CPHD	Center for Policy and Human Development
CSO	Central Statistics Office
CSM	Conceptual Site Model
DACAAR	Danish Committee for Aid to Afghan Refugees
DFID	Department for International Development
DOEHRS	Defense Occupational and Environmental Health Readiness System
DOD	Department of Defense
FOB	Forward Operating Base
GAA	German Agro Action
GIRoA	Government of the Islamic Republic of Afghanistan
HDEP	High Density Polyethylene
HPN	Humanitarian Practice Network
HTH	High Test Hypochlorite
ICRC	International Committee for the Red Cross
IDC	Interest During Construction
IDP	Internally Displaced Person
ISAF	International Security Assistance Force
IWMI	International Water Management Institute
JICA	Japanese International Cooperation Agency
KAF	Kandahar Air Field
MEW	Ministry of Energy and Water (Municipal and Industrial)
MUD	Ministry of Urban Development
NGO	Non-Governmental Organization
O&M	Operation and Maintenance
OXFAM	Oxford Committee for Famine Relief
PDT	Project Delivery Team
RC(S)	Regional Command South
RO	Reverse Osmosis
RRERS	Regional Rural Economic Regeneration Strategies
TDS	Total dissolved solids
THM	Trihalomethanes
UN ESA	United Nations Department of Economic and Social Affairs

UNFPA	United Nations Population Fund
UNICEF	United Nations International Children‘s Emergency Fund
USACE	United States Army Corps of Engineers
USAID	United States Agency for International Development
USBOR	United States Bureau of Reclamation
USGS	United States Geological Survey
USWS	United States Government Inter-Agency Water Strategy
WHO	World Health Organization

1.0 INTRODUCTION

1.1 Regional Setting

Kandahar City, in Kandahar Province, is in the southeastern portion of Afghanistan. Kandahar Province shares an international border with Pakistan to the east and south in addition to sharing a border with three provinces in Afghanistan: Zabul to the east, Uruzgan to the north, and Helmand to the west. The southern portion of the province contains the Registan Desert which is the largest desert in Afghanistan extending west into the Helmand Province. Northern Kandahar Province is characterized by high mountains and rugged terrain. This mountainous region is sparsely populated. Most of the surface water within the Kandahar Province comes from spring snowmelt within the high mountains of the neighboring Zabul Province and farther upstream in Ghazni Province.

Kandahar Province's northern region is made up of primarily three river basins: the Arghandab, Tarnac, and Arghistan. Kandahar City is situated between the Arghandab River directly to the west and Tarnac River located approximately 10 km due east. The Arghistan River is farthest east. South of Kandahar City the Tarnac and Arghistan Rivers flow into the Arghandab River which proceeds flowing west out of Kandahar Province before reaching the Helmand River. The Helmand River flows several hundred kilometers south and west into the Sistan Basin before crossing the border into Iran. See Figure 1, Project Location Map.

The Arghandab watershed is split into the Upper Arghandab and the Lower Arghandab watersheds. The Upper Arghandab drains water upstream of (Band-I) Dahla Dam. The headwaters begin in the Ghazni Province. The Arghandab River flows from Ghazni southwest through the Arghandab and Mizan Districts of the Zabul Province before reaching the Dahla Dam in the Shah Wali Kot District of the Kandahar Province. Land use within the Upper Arghandab is dominated by rangeland (74%), bare soil (19%), and irrigated land (6%) (USACE, 2011).

The Lower Arghandab watershed is defined by the irrigated lands below Dahla Dam. This area extends from downstream of the dam to where the Arghandab River meets the Helmand River – near Qala-i-Bost. There are two main irrigation service canals, which are part of the Arghandab Irrigation Project (AIP) that originate near Dahla Dam. These canals irrigate crops, orchards and vineyards located around the city of Kandahar. Land area of the Lower Arghandab is dominated by bare soil (65%) and irrigated lands (15%) (USACE, 2011).

1.2 City of Kandahar

Kandahar City sits in the north central area of the province directly north of the Registan Desert. It is situated in a relatively flat area where the Arghandab River begins to emerge from mountains to the north. At the western edge of the city a steep bedrock ridgeline, which has a 2-kilometer wide gap, overlooks the Arghandab River and separates it from the city. Northern Kandahar City is elevated higher and elevation gradually drops from north to south.

Kandahar City is the capital of Kandahar Province and the second largest city in Afghanistan. The city is divided up into 10 districts with multiple neighborhoods in each district. See Figure 2, District Boundaries Map. In recent years, the city has experienced population fluctuations due to influxes of displaced persons and refugees caused by war and drought. In general, the poorest neighborhoods are located in the north and more affluent neighborhoods are located in central and southern Kandahar City closer to commercial development and the market with new development in the east. The entire city experiences lack of water supply to meet basic daily needs, however there is an existing distribution network that was constructed decades ago which has since seen minimal improvements. Production wells feeding the system run intermittently and some have ceased operating completely. Those without access to the distribution system use privately dug wells or collect surface water from canals originating from the Arghandab River. Water quality is poor due to lack of treatment. Groundwater is reportedly brackish and contains biological contaminants because wastewater infiltrates the shallow aquifers, which is where most wells in town draw their water supply.

1.3 Study Authority

The U.S. Army Corps of Engineers (USACE), Afghanistan Engineer District-South (AED-S) was requested by the International Security Assistance Force (ISAF) Regional Command South (RC(S)) to develop a Water Supply Master Plan for Kandahar City which currently has an estimated population of about 675,000 people. As reported in the *2010 Afghanistan Development, U.S. Efforts to Support Afghan Water Sector Increasing, but Improvements Needed in Planning and Coordination* report, GAO-11-38, the U.S. Government Inter-Agency Water Strategy (USWS) for Afghanistan is guiding the strategic approach behind U.S. water sector development efforts in Afghanistan through fiscal year 2014. One of the primary goals within this document is to expand access to safe drinking water supply and sanitation, including better hygiene.

The Commander‘s Emergency Response Program (CERP) has been the primary funding source for the Department of Defense‘s (DOD) efforts to improve the Afghan water sector. The intent of CERP is to provide a quick and effective method for projects that will provide an immediate positive impact on the Afghan people. CERP funds provide a means to conduct stability tasks, including the reconstruction of infrastructure, restoration of public services, and support to economic development (United States Forces - Afghanistan, 2011).

1.4 Study Purpose and Need

The purpose of this Master Planning document is to present the findings of a planning study which was conducted to provide decision-makers recommendations to improve the water supply situation in Kandahar City. The purpose of the project is to identify alternative(s) to provide access to a safe and sustainable water supply as quickly as possible and in the long-term in order to accommodate the existing and future population of the city. The USACE Project Delivery Team (PDT) consists of several Continental United States (CONUS) USACE Districts and USACE AED-S working on behalf of ISAF RC(S). Working within this study purpose the USACE PDT efforts have focused on identifying existing conditions, evaluating options for water supply, and recommending a plan for implementation phases. Recommended plan(s) must be technically feasible, environmentally and socially acceptable, cost-effective, and supported by ISAF and local Afghan authorities.

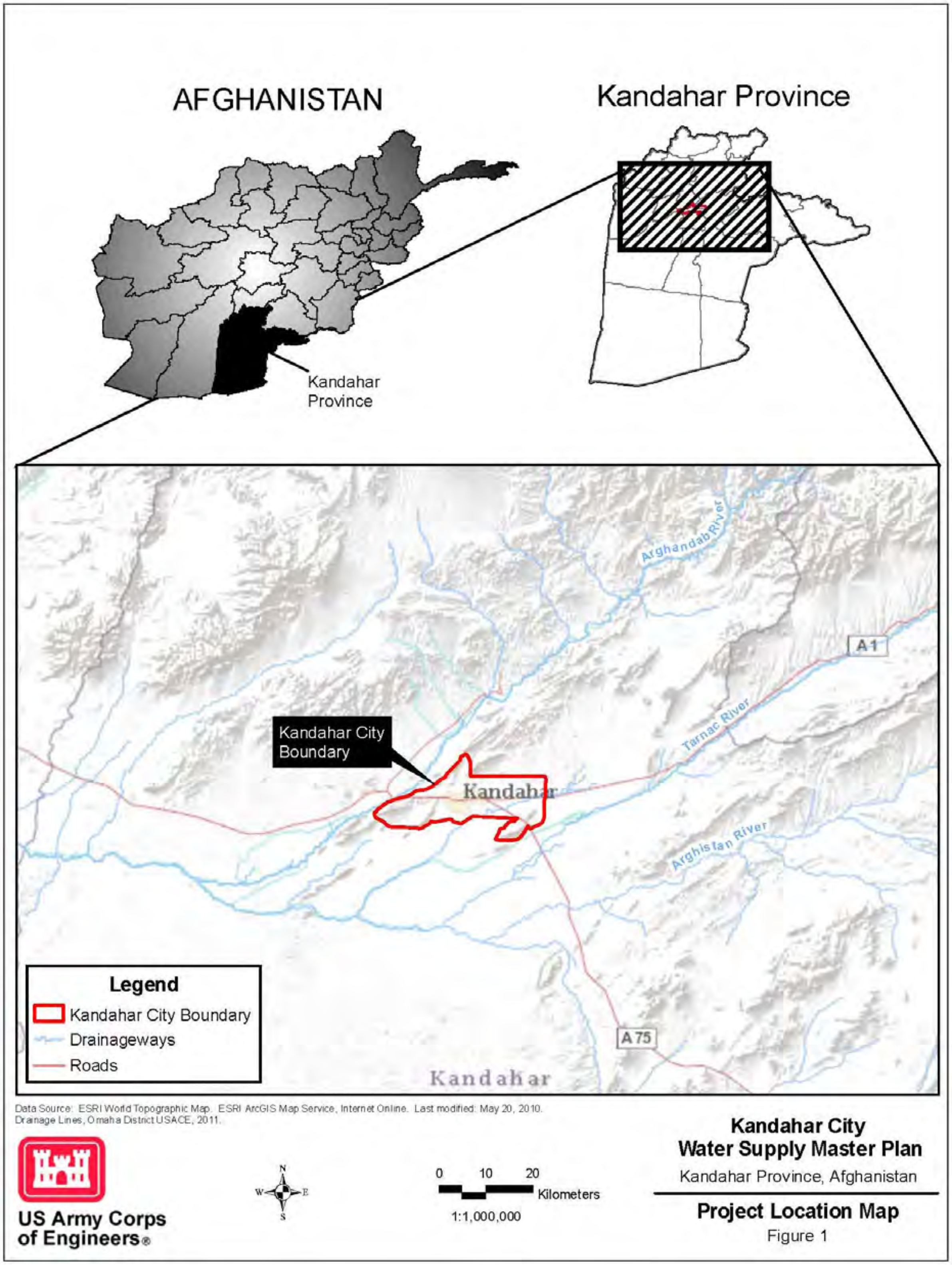


Figure 1. Project Location Map

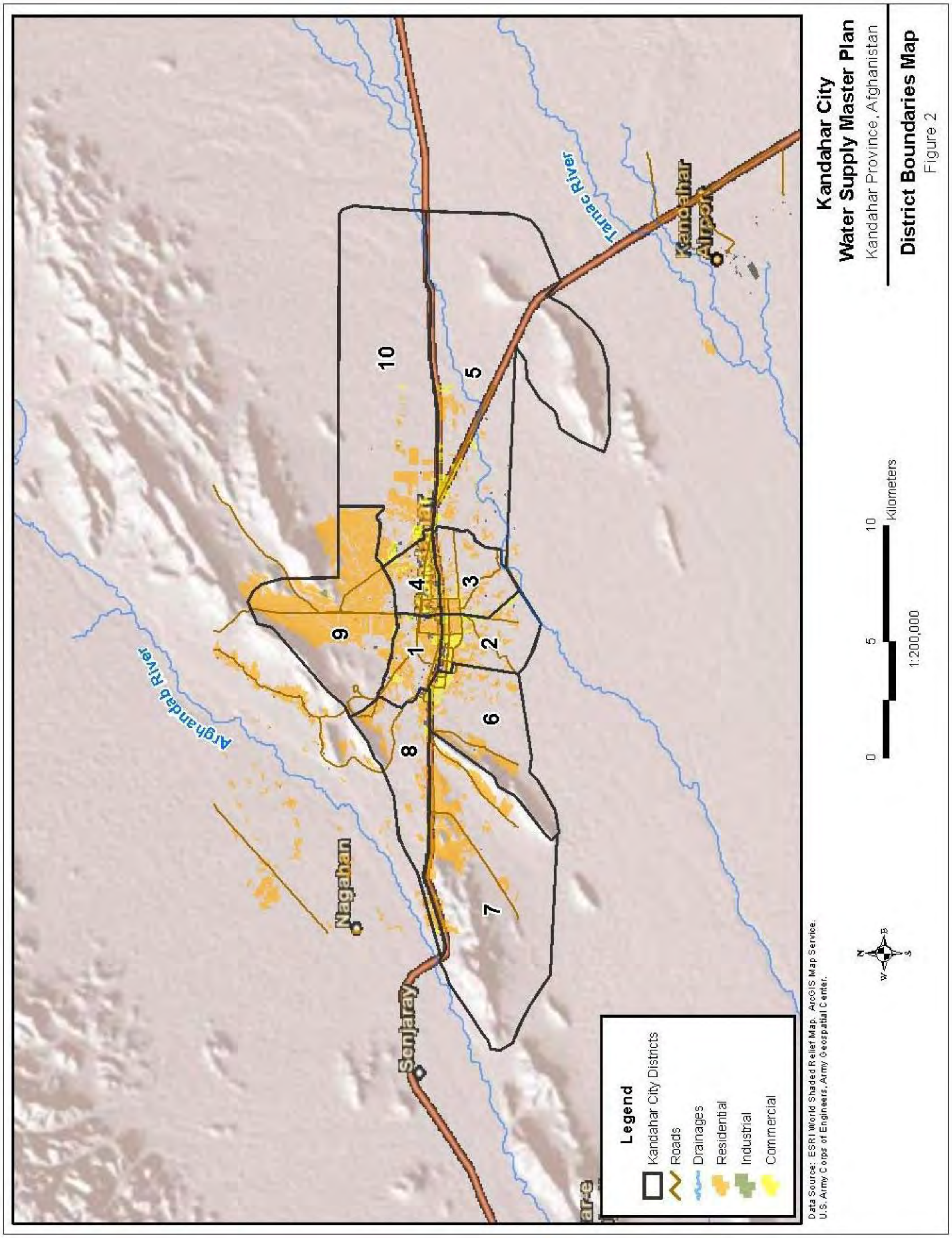


Figure 2. District Boundaries Map

Improvements to the water supply situation in Kandahar City are needed due the degraded condition of existing infrastructure. Over time the city has been impacted by decades of war and drought. A lack of basic access to a public water supply network and areas that are served suffer from severe deterioration of infrastructure which leads to high rates of system losses and possible contamination through infiltration of runoff. Most of the city obtains its water from private wells which draw from shallow aquifers beneath the city. Due to the lack of solid waste and wastewater treatment systems wastewater infiltrates into and contaminates water in the shallow aquifers. Increased development of household wells has also depleted the shallow aquifer and caused lowering of the water table in the city.

Water supply improvements are also needed due to poor water quality in existing supplies and the lack of adequate water supply. Existing sources of water supply in the city consist of groundwater from shallow aquifers and surface water from the Loy Walla Canal, both of which are not treated prior to consumption. The quality of groundwater is particularly suspect due to infiltration of wastewater into the shallow aquifer. The contaminated groundwater is the primary water source and is a health hazard. Outbreaks of diarrhea and other sicknesses are linked to consumption of this water source, particularly with respect to children.

During periods of drought, the reduced availability of water for agriculture has led to a rural population migration to Kandahar City. Prolonged war and poor economic conditions have caused an influx of refugees and displaced persons. Currently, the city cannot meet the basic needs of the existing population, creating difficult conditions for new arrivals that already face socio-economic challenges. Water insecurity contributes to Kandahar City's social instability and lack of development opportunity. The rapid increase in population has occurred on the periphery of the city where access to water is most limited. Lack of access to water contributes to both unemployment and high rates of poverty as well as increased tensions among existing residents and new arrivals.

1.5 Prior Studies and Reports by Others

Many components of this Master Plan either have been or are currently being addressed at some level by the Afghanistan Urban Water Supply and Sewerage Corporation (AUWSSC), local government, stakeholders, independent government organizations, and non-governmental organizations (NGOs). Their work will be acknowledged throughout the document when incorporated, including work already presented in other feasibility and groundwater studies.

Most prior efforts have been a combination of planning, engineering and design, construction, and capacity building assistance conducted over the last decade. Technical reports and planning documents have been located to the extent possible, reviewed, and utilized in a careful and rational manner. Previous studies and reports have been obtained from local Afghan authorities, consultants, and international sources. Inquiries made to Afghanistan ministries have been useful and continue to reveal new information regarding on-going efforts and historic documents. However, conflicts such as wars dating back over thirty years have impeded record keeping by local authorities and the overall availability of water resource data is minimal. Lack of historical water resource, municipal infrastructure, demographic, and social data coupled with the constraint of conducting planning activities in the middle of a military conflict zone made assessing the existing conditions challenging. Recent efforts by the United States Agency for International Development (USAID), Canadian International Development Agency (CIDA), Japanese International Cooperation Agency (JICA), various agencies within the United Nations, and many foreign and domestic NGOs have supplied the majority of the information for the development of this report.

2.0 DEMOGRAPHICS AND ECONOMY

2.1 Population Estimate

An accurate population estimate and projection will provide an essential piece of information for estimating water consumption and demand for the Kandahar City Water Supply Master Plan (Master Plan). For planning purposes population estimates will be forecasted to the year 2030.

After fully considering the demographic information available, the Master Plan PDT recommended using an existing population estimate for Kandahar City of 675,000 in 2011 and an estimated growth rate of 3%. Using an exponential growth model to project population the estimated population in year 2030 is 1,184,000. The following sections describe how these estimates were determined and the difficulty of determining these estimates. Additional information is available in Appendix A.

2.1.1 Prior Studies and Reports

In order to develop a population estimate for this Master Plan, approximately 12 water studies previously conducted on Kandahar City were consulted, with the oldest being from 2003. The following is a discussion of relevant population estimate and growth information that was captured from these reports. Appendix A contains a detailed annotated bibliography of the reports that were consulted. For each report, any information pertaining to population size, population growth rates, and population for districts has been captured. Additionally, information on water demand or water consumption was also captured.

2.1.2 Summary of Existing Population Estimates

Table 1 shows a summary of population estimates and Table 2 shows a summary of growth rates derived from the sources in the previous section.

Table 1. Summary of Population Estimates for Kandahar City

	CSO	USAID	Beller, Kocks, and BETS	UN-HABITAT	CIDA
2002	26,760				
2003		500,000			
2004	468,200				
2005			537,000		
2006				800,000	
2007				600,000	
2008					600,000
2009				500,000 – 600,000	600,000

Table 2. Summary of Growth Rates for Kandahar City

Source	Base Year	Population	Estimated Growth Rate
Beller et al. (2005)	2005	537,000	1.8% (2005-2024); 2% (2011-2024)

CDM (2006)	2000	NA	3.25% (2000-2004)* 2.92% (2005-2009) 1.6% (2010-2014) 1.37% (2015-2019) 1.11% (2020-2025)
CIDA	2008	600,000	3% over 20 years
CIDA	2009	600,000	3% over 20 years

*Rural Growth Rates

2.1.3 Data Gaps and Uncertainties

Data gaps and uncertainties point to deficiencies in many of the previous reports and explain why it is extremely difficult to assess the quality of the population estimates or to compare these reports against each other. A summary of the data gaps and uncertainties follows:

1. Lack of stated methodologies in many of the previous reports
   As shown in Tables 1 and 2, there is a large range of values for the population and population growth estimates for Kandahar City. Most of the reports do not provide any substantive description of their methodologies for making these estimates. Many of the more current reports rely on population information from previous reports, so there is little in the way of new information.

2. Difficulty of incorporating displaced persons into the population estimates
   Another issue is the internally displaced persons (IDPs) and refugees. According to ancillary sources, Kandahar City has grown significantly in the past five years due in part to IDPs. It is difficult to assess whether IDPs are included in the population estimates of the reports that were reviewed. It does not seem likely.

3. Lack of common definition of Kandahar City amongst reports
   Another reason for the varying estimates is the lack of a true definition of Kandahar City. It is unclear whether all of these reports are referring to the same geographic extent for Kandahar City. There was limited availability of maps in any of these reports depicting the extent of their study areas. Therefore, a lack of a common definition for Kandahar City may account for some of the variability in the numbers.

4. Lack of population detail for Kandahar City at the district level
   There is limited information in existing reports or documents discussing population counts and growth rates for Kandahar City's ten districts. For planning a water distribution system, this information is essential. Components of information are available occasionally, but they are usually for only one or two districts making it difficult to derive a comprehensive picture at any point in time.

5. Contribution of existing conflict to population instability
   Given that Kandahar City is located in one of the most hotly contested regions in Afghanistan, the population can vary quite a bit depending on the status of the conflict. While the Beller et al. report may have been a very accurate report for its time, six years have passed since then. During the past five years, the conflict with the Taliban has resulted in an influx of people into Kandahar City. In December 2010, The Institute for the Study of War published a report titled:

Counterinsurgency in Kandahar: Evaluating the 2010 Hamkari Campaign (Forsberg, 2010). This report states that: ―Kandahar City itself has seen significant growth in the past five years, as displaced persons moved to the city to escape conflict in outlying districts." How much growth is not stated, but assuming a constant growth rate of 2% may be risky over that five-year period.

2.1.4 Recommended Population Estimate and Growth Rate

The recommended baseline population for this Master Plan is 600,000 beginning in 2007. This estimate is consistent with the estimate given in the UN-HABITAT report which is cited by subsequent Kandahar water studies, so there is reasonable justification for using this report (Klimento & Baker, 2008; Yuma Engineering & Saxe Engineering, 2009). This is a higher baseline population than what the Beller et al. study used. As previously discussed, there are many challenges associated with estimating Kandahar City‘s population, including the lack of information on IDPs. Because of the nature of the conflict with the Taliban in Afghanistan and tendency of IDPs to migrate towards population centers, it is possible that this baseline estimate recommendation is low.

Due to the circumstances of the current conflict with the Taliban and the upside potential for population growth, the Master Plan utilizes a growth rate of 3% as the population growth rate for Kandahar City. Population growth rates used in prior studies varied widely as well. Beller et al. assumed a growth rate of 1.8% for 2005-2010 and 2% for 2011-2024. More recent studies, such as the 2008 and 2009 CIDA studies, have used a 3% growth rate (Klimento & Baker, 2008; Yuma Engineering & Saxe Engineering, 2009). Finally, the United Nations‘ Department of Economic and Social Affairs (UN ESA) report came up with a differential range of values as follows: 2000-2004, 3.25%; 2005-2009, 2.92%; 2010-2014, 1.6%; 2015-2019, 1.37%; and 2020-2025, 1.11% (CDM, 2006).

In developing the report, information explaining the exploding population of Kabul was available. According to the World Bank – South Asia, Kabul grew by 15% per year between 1999-2002 and continues to grow by 5% or 150,000 people each year (2% migrants and 3% natural growth) (World Bank, 2005). Also, the Humanitarian Practice Network (HPN) reports that Kabul‘s population tripled between 2001 and 2009. The most significant component of population growth was returning refugees, displaced persons, and migrants – this group accounted for roughly 80% of the population growth in Kabul (Setchell & Luther, 2009). While Kandahar City is not Kabul, Kabul‘s experience gives reason to be cautious regarding population growth.

Under normal circumstances, 2% would be a reasonable growth rate for a city like Kandahar if it were experiencing a natural growth rate. While there is a component to Kandahar City‘s growth that will be natural, the highly volatile conflict environment does not lend itself to a predictable natural population growth rate. For planning purposes it seems likely that the growth rate for Kandahar City will exceed 2% due to IDPs and refugees. If access to safe drinking water is provided throughout the city, this could serve as a potential magnet for even more internal migration.

Using a population estimate of 600,000, as of 2007, and assuming an exponential growth rate of 3% this provides a 2010 population of 655,636. Table 3 presents the projected population from 2010 through 2030 using these parameters.

Table 3. Population Projections for Kandahar City

Year	2007	2010	2015	2020	2025	2030
Population Estimate	600,000	655,636	760,062	881,120	1,021,460	1,184,152

It is recommended that when time and resources permit, a more detailed population assessment be performed in order to get a more precise estimate of population and population growth. As the water distribution network is developed in subsequent phases, it may also be possible to assess the effect of this new or improved network on population dynamics (e.g. serve as a magnet to draw even more people into Kandahar City).

2.1.5 Population by District

As noted above, it was difficult to capture a comprehensive picture of population estimates and growth rates at a point in time because of limited information. Population densities for each district were calculated to estimate water demand within each district for purposes of the water distribution model. See Section(s) (identify the section number here) of the report.

2.1.6 Priority Service Areas

Areas without access to piped water are highest priority for future service. These areas tend to be located on the periphery of the city and populated by lower socio-economic groups, refugees, and displaced persons. Due to lack of treatment of the existing supplies, the water being provided by municipal wells is considered to have higher chance of being unsafe and unfit for human consumption, meaning these areas also are in urgent need of improvements to water supply services.

2.2 Social Aspects of Water Access in Kandahar City

Water security and human security have been and continue to remain inseparable. This relationship is especially pertinent for countries experiencing war and internal conflict. The *Afghan Human Development Report* (Center for Policy and Human Development, 2011) asserts that water security is integral to human development and that prospects for peace in Afghanistan are contingent upon improving access to water for drinking, agriculture, and sanitation. Providing equitable and shared access is thus critical for stability and reconstruction of Afghanistan (JICA, 2003). In Kandahar City, the existing distribution network covers only about 20% of the city.

With inadequate water access, drought, and poverty prevalent in the country, Afghanistan‘s potential for reconstruction is reliant upon social stability at the community level, scaling up to the national level. Within Kandahar City specifically, internal social stability and development are contingent upon realizing water security for all residents including IDPs and Kuchis. Kuchis are a nomadic population located on the outskirts of the city. Implementation of the Kandahar City Water Master Plan should take social factors into consideration in order to maximize positive effects and mitigate potential negative second and third order effects of installation. The following sections provide a contextual overview of the current situation within Kandahar City.

2.2.1 Drought, Water Access Rates and Poverty

Approximately 70% of people living in Kandahar Province are at extreme risk of food insecurity. The 2001 drought devastated the local economy of Kandahar Province with reports of 76% of livestock slaughtered or sold below average price by 40% because of the loss in weight among animals and decline in demand. Wheat production also fell by over 40% (Qureshi & Akhtar, 2004). A 2004 post-drought assessment indicated that aid to those afflicted was only reaching those situated on main roads with the perception that aid was distributed unfairly (CPHD, 2011; Qureshi & Akhtar, 2004). Kandahar City is classified as a ‗low-income' city with families having a modal income between 1 and 5,000 Afghani's (Beller et al., 2005).

Effects from the 2001 drought are still rampant. The JICA (2003) reports that many displaced persons from rural areas have come to and live in the periphery of Kandahar City, usually in areas with limited access to water. This reportedly caused a rapid increase of population in and around Kandahar City, which has seen massive influx of people in the last five years (Forsbeg, 2010).

Water access rates within the city are extremely variable with estimates of coverage of piped water ranging between approximately 50,000 to 100,000 residents (Beller, et al., 2005; Afghanistan Investment Support Agency, n.d.). However, lack of water distribution system and well data is prohibitive and unreliable for decision-making, particularly with respect to making repairs. Due to the poor coverage of existing water infrastructure, over 78% of Kandahar City residents have installed their own private wells (Beller, et al., 2005). The installation of so many wells has led to the drawdown of groundwater resources, exacerbated by local climate patterns.

In addition, Kandahar City is also characterized by extreme poverty and high rates of unemployment. Waldman (2008) suggests both poverty and unemployment are exacerbated by the lack of access to water and puts the region at risk of further destabilization. ―[Afghan] focus groups… link unemployment to criminality, disputes, and violence, particularly over resources…as one man said, ‗most of the conflicts in our area are on water and land and this is among people who are jobless.' Prior to understanding the social dynamics surrounding inadequate water access in Kandahar City, it is imperative to understand the cultural context that water has within Kandahar City."

2.2.2 Water and Islam

Water has a distinctive role in the Islamic faith, practiced by the majority of Kandahar City residents. Water is commonly understood as a public good or common property. One Afghan respondent[1] refers to the religious tenets within Islam that compel local residents to share drinking water supply:

> People who are rich, and have their own source of water, with deep wells in their houses support poor people by providing free water. This is based on religious belief of Muslims of *hyrait*. That is, people who are rich, support poor based on this idea. There are two types of *hyrait*: *zakat* and *shukan*. *Zakat* is based on money meaning land, garden, food with implied limitations. *Shukan* means that you ‗pay it forward'. *Hyrait* however only applies to ‗rich' people. Poor people don't need to do *hyrait* because they don't have money; it is mostly based on what the individual thinks they can pay and there are no limitations unlike *shukan.*

Based on this viewpoint, it appears that local residents are more likely to share drinking water between settled residents of established households. However, more research needs to be done to document whether these religious tenets hold true for residents of informal settlements and IDPs where reports of conflict over water are more common. Additionally, the various uses of water within the household and other major consumers are not well known in the Afghan context and accordingly more research is necessary. For the purposes of this analysis, water for domestic use and agricultural use appear to be two major consumptions of water in Kandahar City.

[1] The following is a summary of conversation between a local Afghan respondent and interviewer, 2011.

2.2.3 Social Dynamics

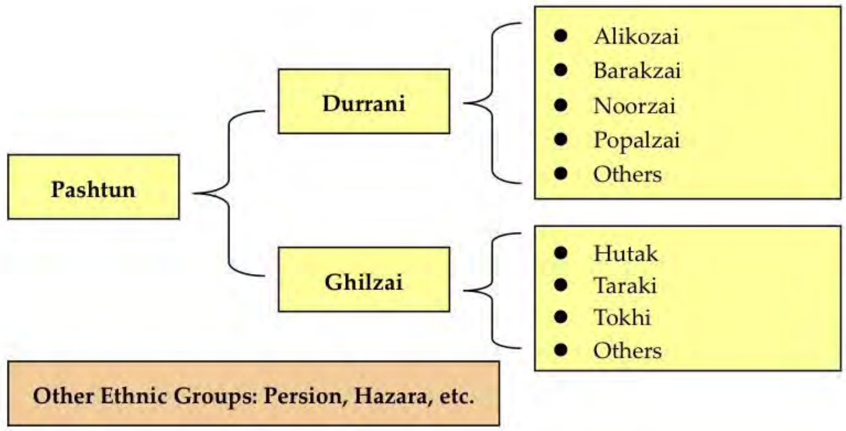
Kandahar City appears to be relatively ethnically homogenous with the majority of current residents of Pashtun descent (Afghan respondent, personal communication, 2011). However, the city recently experienced increased in-migration of individuals seeking jobs, access to better resources including water and to escape conflict. Kandahar City has often been referred to as a worsening situation of internal displacement and remains a destination of choice among IDPs for the previously mentioned reasons. In-migration to the city will continue to increase until security improves and related livelihood opportunities are improved elsewhere (Schmeidl, Mundt, & Miszak, 2010). IDPs within Kandahar City are not officially acknowledged and their presence remains exceedingly controversial for a variety of reasons. Perhaps the most significant reason is if the local government officially recognizes their presence, an obligation of assistance is implied. According to the United Nations Office for the Coordination of Humanitarian Affairs (2010), internal displacement in Afghanistan is highly politicized and controversial because no organization has the mandate to assist the IDPs.

Potential for Conflict and Inequitable Water Sharing: IDPs, Kuchis and Agricultural Users

As a society fractured by war and conflict, the security of Afghan residents depends on correcting insecurity. Internal insecurity is plagued by poverty, unemployment and lack of access to basic essential services such as water. Inequitable water sharing has a direct correlation to the disempowerment of communities without access, and there is potential emergence of conflict over water. Due to the inability of local institutions to provide services combined with the trend towards water-intensive crops, water sharing has become highly inequitable and a source of intercommunity tension and conflict (CPHD, 2011). This is echoed from a farmer in Kandahar City (CPHD, 2011).

> The government should help us obtain water in accordance with the size of the lands we own. At the moment, some people who have only 5 jeribs of land take all the water for themselves, while a village with 50 to 100 jeribs of land receives only enough to irrigate 1 jerib. This injustice in water distribution causes conflicts. But, when we ask the government to do something for us, the most they do is write it all down on paper; no practical steps are ever taken. The other problem is that they don‘t have professionals and specialists on their staffs.

Understanding the identity of groups living within Kandahar City receiving access to water supply/services is perhaps the first step in mitigating potential water conflict. The majority of the Kandahar City residents appear to be Pashtun (95%). The Pashtun can be further sub-divided into sub-categories as illustrated in Figure 3.



Source: JICA, 2003

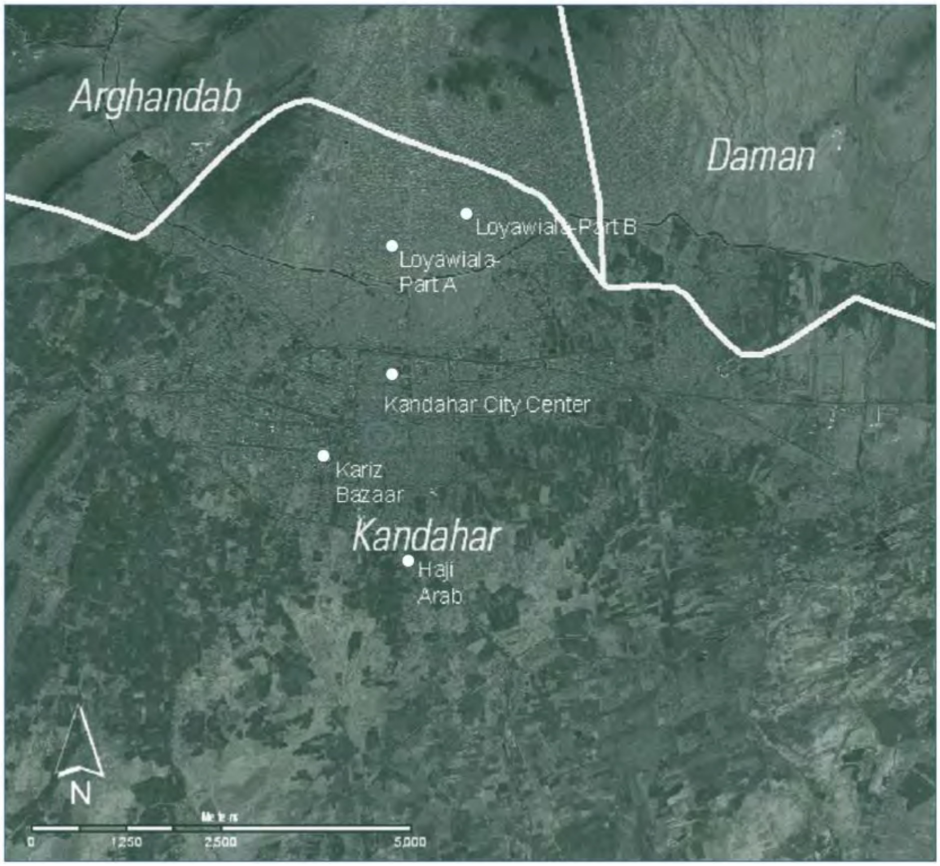
Figure 3. Identity Groups within Kandahar City

A 2007 Oxfam survey of 500 Afghan residents indicates that local disputes are related to resources, specifically land and water which are in turn further aggravated by ethnic, tribal and inter-community differences (Waldman, 2008). Thus, it is imperative to understand the relationship among Kandahar City settled residents and informal residents (IDPs and Kuchis) in order to mitigate water‘s role as the second major cause of disputes in communities. Approximately 40% of survey respondents said that the cause of conflict was attributable to a perceived lack of sufficient water to meet their needs and poor infrastructure that limited their control over the water supply (ibid). Although water is not the singular cause of disputes within the community, it has the potential to massively exacerbate fragile relationships between Kandahar City formal and informal residents. More research needs to be performed within Kandahar City to diagram the local relationship between conflict and water. The potential conflict over resources by marginalized residents including IDPs and Kuchis combined with current conflict over agricultural use is a situation that requires monitoring.

Internally Displaced Persons

Kandahar City has witnessed an increase in IDPs and their presence is very much tied to water. Access to water was identified as one of three main needs among returning residents according to the Cooperation for Peace and Unity (CPAU) (as cited in CPHD, 2011). Limited information exists on the identity of recent IDPs and more permanent IDPs. According to current estimates, the number of IDPs in Afghanistan is estimated at about 300,000 by the UN Refugee Agency and over 450,000 by the Ministry of Refugees and Returnees. Within Kandahar City specifically, there are estimates of 10,000 IDPs according to Schmeidl et al (2010).

Most IDPs and other migrants settled in an area slightly north of District 9 or Loya Wiala within Kandahar City. This area specifically remains of most concern to stability efforts of local and national Afghan authorities. It remains mostly under insurgent control (Woodward, 2010). There are three other areas where IDPs have settled. These three areas include: Kariz Bazaar, Haji Arab and Maji Mirza Khan. Several locations of these IDPs are shown in Figure 4.



Source: Schmeidl et al., 2010

Figure 4. IDP Concentrations in Kandahar City

IDPs lack political representation and thus remain politically and geographically marginalized with potential hostility from Kandahar City residents. Although Kandahar City IDPs were able to form a shura (i.e., a community gathering led by local leaders) to request provincial support for increased water provision, this relationship is tenuous at best and subject to the ability of local IDPs to negotiate with local authorities (Schmeidl et al., 2010).

The Oxfam Afghanistan study indicated that Kandahar Province was an extreme risk of insecurity for various reasons. The disruption of established patterns of water service provision, poor management, insufficient irrigation and environmental degradation underscores water‘s role both domestically and agriculturally. The high economic costs associated with gaining access to water in these settlements puts a severe burden on Kandahar City‘s informal residents (ibid), which increases the challenge of improving social cohesion and access to potable water. Narrative from an individual from an IDP camp highlighting water conflict is detailed below (CPHD, 2011).

> Many conflicts take place among community members; the families further away from water-points usually come here to get water, but there is not enough water for all households. This creates conflict, and, once, three people were injured by others with knives because of disputes over water.

Kuchis
Even less information is known about the Kuchi or nomadic population. These nomads tend to live on the outskirts of the city (United Nations Office for Coordination of Humanitarian Affairs as cited in Schmeidl et al., 2010). According to the Kandahar Provincial profile, migration rates vary between winter and summer: in winter, approximately 80,000 stay within the city and in summer this number decreases to approximately 40,000. One Kuchi man described the Kuchi marginalization: ―We are Kuchis. We do not have our own water, and the owners of the karezes do not give us water" (CPHD, 2011). A kareze is a traditional method of irrigation that conveys groundwater through a gently sloping tunnel to the surface.

Research indicates that throughout the country, Kuchis tend to have the least access to improved water sources and are the largest population segment that travel one to three hours to collect water. This is more than four times longer than the national average (CPHD, 2011). A report by Qureshi and Akhtar (2004) indicates that Kuchis were significantly affected by the 2001 drought, were displaced in large numbers from their normal grazing routes and had to sell livestock at 40% of cost and in some cases exhausted their entire herds. Additional research is imperative to understand the exact location of Kuchis within Kandahar City, their access to water and interaction with IDPs and the city's formal residents.

Agricultural Users
Irrigation for agriculture is Kandahar City's other major consumptor of water. Currently, there is inequitable water sharing between farmers within Kandahar City and its surrounding regions. Reflections from local Kandahar City farmers are highlighted below (CPHD, 2011).

> …during drought or water shortages at the river and the canals, upstream farmers would put obstructions in the canals to divert more water for their own benefit. They do not respect the water turns that have been decided. This causes lots of problems for downstream farmers, and it leads to conflicts.
>
> Combined with collapse of local government capacity to support *mirabs*[2] and local institutions, the erosion of social capital has led to an increase in illegal practices. These include expansion in cultivation of water-intensive crops, such as rice or cotton, in the head reaches of canals; the unregulated construction of new off-takes, which allows upstream farmers to siphon off more water, and the proliferation of mills and micro-hydropower units, which increases the demand…

Overall, there is immense potential for future conflict between agricultural users, formal residents and informal residents including IDPs and Kuchis. This situation is one that needs to be carefully monitored in order to not exacerbate existing inequity or introduce new conflict.

2.2.4 Conclusion

The installation of any new water infrastructure within Kandahar City must take socio-economic dynamics into consideration. This intervention must have net positive benefits and seek to avoid and mitigate potentially negative second and third order effects. Through the building of new water infrastructure, it becomes possible to create more favorable conditions for controlling water (CPHD, 2011) equitably if the implementation of the Master Plan is done so in a participatory and consultative process.

[2] Mirabs manage water distribution and allocation along canals in rural areas.

The following list of recommended actions may be beyond the scope of the Master Plan but provides a good baseline with which to achieve equity.

1. Understand the various competing uses of water including but not limited to household domestic use, IDP/Kuchi use, agricultural use and other major Kandahar City uses of water.
2. Pay attention to demand management strategies that do not compromise various sectoral uses of water.
3. Improve local water governance and collective water management practices.
4. Establish Water User Associations to determine placement and ownership of water infrastructure.
5. Develop drought mitigation plans.

According to a recent report on urgent rehabilitation programs, JICA (2003) suggests that local shuras and jirgas have an important role in local planning, development, and dispute resolution. Reliance upon these local mechanisms would help ensure that this Master Plan remains both culturally appropriate and meets current demand. Demand driven development is more sustainable and beneficial for Kandahar City residents and “community-based initiatives should be supported, as these initiatives are necessary for strengthening local governance and achieving tangible results in communities across a variety of sectors to be priorities by the communities themselves…it is essential for harnessing the social capital needed to improve living conditions” (JICA, 2003) of all formal and informal settlements and sectors in Kandahar City.

Enhancing reconciliation among the various groups within Kandahar City is vital to that city‘s rehabilitation, security and stability. In order to provide water in an equitable fashion, it is imperative to achieve this. Global evidence exists that in the absence of viable institutions, shifts in water use and water availability can generate conflict, (CPHD, 2011) and if water development projects are undertaken without community cooperation, tensions may increase.

Despite the religious edicts regarding water sharing in Islam, research in Kandahar City and Afghanistan indicates that informal settlements of IDPs and Kuchis are somehow exempt and experience conflict over equitable water sharing. Installation of infrastructure would perhaps be of most beneficial impact within the region of District 9. It remains to be seen, however, whether residents would be able to pay for services. Full-cost recovery may not be possible.

The added component of climate variability within the region is also of extreme importance, and any water infrastructure plans must be climate resilient.

2.3 Local Economy

2.3.1 Prior Reports

Socio-economic and demographic profiles were developed for Kandahar Province through a collaborative effort of the United Nations Population Fund (UNFPA), the Government of the Islamic Republic of Afghanistan‘s (GIRoA) Central Statistics Office (CSO), and numerous stakeholders. The following information is retrieved from that assessment in addition to the Regional Rural Economic Regeneration Strategies (RRERS) Provincial Profile for Kandahar Province which contains information on industrial and commercial activities in Kandahar Province. Table 4 below provides a summary of products produced in Kandahar Province.

Table 4. Products from Kandahar Province

Subsis-tence Crops	Industrial Crops	Fruits	Vegetables	Herbal Products	Handicrafts	Small Industries	Animal Products
Wheat	Cotton	Grapes	Potato	Caray	Carpets	Honey	Eggs
Corn	Sugar Extract	Pomegranates	Onion	Licorice Root	Shawl Making	Karakul Skin	Dried Yogurt
Maize	Sugar Cane	Melon	Tomatoes	Asafetida	Embroidery	Dried Sugar	Yoghurt
Rice	Sesame	Orange	Carrots	Zerk	Pottery	Confection	Whey
Beans	Tobacco	Almonds	Cauliflower	Aniseed	Pelisse	Sugar Candy	Milk
Vetch	Olives	Walnuts	Spinach	Hyssop	Jewelry	Sugar Sweet	Butter
Peas	Sharsham	Mulberry	Leek	Chicory	Rugs	Silk	Wool
Other	Other	Other	Other	Other	Other	Other	Other

Source: UNFPA, n.d., p.44

Kandahar Province has both agricultural and industrial enterprises. Within Kandahar Province, the majority of economic activity is in the districts of Maiwant, Zhire, Panjwayee, and Kandahar, and the majority of commercial activity is related to trade and services and agricultural and livestock products. The major crops are wheat and maize and are found in more villages than the other crops. Kandahar District produces a large amount of wheat, maize, okra, green gram, poppy, onions, tomatoes, and leeks; however the most popular agricultural activity is producing animal products (UNFPA, n.d.; Afghanistan Investment Support Agency, n.d.).

Kandahar Province has two agricultural research farms. Tarnac Farm is near the Kandahar Airport but lack of water, funds, and planning contribute to a lack of well trained staff. Nawrozi Farm is located west of Kandahar City but suffers from many of the same problems as Tarnac Farm (Afghanistan Investment Support Agency, n.d.).

Based on research conducted for the Master Plan the following industries were identified to be occurring within the Kandahar City area (UNFPA, n.d.; Afghanistan Investment Support Agency, n.d.):

- Automobiles and spare parts
- Medicine
- Food items
- Importing and exporting (trade)
- Blacksmithing
- Jewelry making
- Machining
- Crafts
- Electronics repair
- Clothing shops
- Food service
- Clothing and textiles

2.3.2 Institutional Constraints

According to the Union of Industries, Farmers, and Businessmen, businesses have identified the following operating problems:

- Inadequate and less supportive governmental policies in particular in terms of taxation
- Lack of reliable power and accessible roads
- Air transport is very expensive and then Kandahar Airport is not allowed to be used by civil aviation
- Lack of storage capacities, both dry and cooled
- Lack of facilities in the industrial park, power, water, drainage, roads, security, etc
- Government bureaucratic procedures
- Lack of quality control and standardization procedures
- Lack of supporting mechanism in the government
- Lack of financing mechanisms and institutions
- Afghan transport is not allowed into Pakistan and Iran which creates problems in particular for transport of fresh food, has to change goods from one truck to the other in border, while Pakistani trucks are allowed to cross the border and come inside Afghanistan
- Lack of technical and professional agriculture extension workers (Afghanistan Investment Support Agency, n.d., p. 8)

2.3.3 Key Economic Development Opportunities

According to the Afghanistan Investment Support Agency (n.d.), there are numerous opportunities for potential development in the Kandahar Province. These opportunities include:

- Reducing the demand for water in the agricultural sector by utilizing more efficient practices such as drip irrigation and replacing wheat crops with higher dollar value and more drought-resistant crops;
- Increasing the ability to trade goods and services by improving infrastructure around the province;
- Boosting milk production by replacing current cow herds with higher yielding dairy cattle;
- Developing the fish farming industry by using salinated drainage water not suitable for crop irrigation;
- Increasing meat and wool production by reintroducing sheep breeding flocks;
- Improving the livelihoods of indigenous people by building business centers where products (i.e., carpets, food items, etc.) can be sold;
- Establishing a tree nursery industry by growing trees that can be sold to farmers for re-planting drought-ravaged orchards; and
- Re-establishing poultry development by ―back-crossing commercial hens with local cocks to increase rusticity and restore the capacity for broodiness” (p. 11).

2.3.4 Conclusion

Accurately quantifying specific economic benefits in a hostile, war-torn environment with very limited detailed economic resources was difficult and therefore led to generalities. Undertaking a trade-off analysis or cost-benefit analysis can be an important tool in developing a water strategy, allowing consideration of various benefits derived from water supply in the industrial and commercial sector. Strategically providing funding to various sectors of the economy will allow for a more accelerated, economically justifiable, and sustainable water strategy. Examples include water investments in Karnataka, India, and Senegal that had an estimated economic internal rate of return of 20% and 13.7%, respectively (World Bank, 2001; World Bank, 2004).

3.0 EXISTING PHYSICAL AND ENVIRONMENTAL CONDITIONS

Kandahar is a province with limited water resources. Arid climate, variable precipitation, and periodic droughts all make it difficult to predict the availability of water in the region over time. Management of the various water resource systems in the province is currently neither integrated nor sophisticated. Through research, technical analysis, and coordination with various local and international officials, this plan identifies the important factors to consider when making decisions regarding water supply development in Kandahar City.

3.1 Topography

The study area lies within the northeast part of the Helmand Basin and occupies three physiographic provinces (Abdullah & Chmyriov, 2008). From west to east, these are:

- Helmand-Arghandab Uplift: Forms the western side of the study area and contains the upper and lower Arghandab watersheds and Kandahar City.

- Dari Rod Trough: Forms most of the middle part of the study area. The trough is bounded on the east by the Mokur Fault and on the west by the Chaman Fault. Rivers, including the Mokur and Tarnac Rivers, follow fault zones within the trough. The Registan Desert covers most of the study area south of the Dori and Arghandab Rivers.

- Alpine Folding: East of the Chaman Fault, the study is characterized by low parallel ridges and valleys in the south, and the Sardih wa Ghazni Rod watershed to the north. The Gardez River and Ghazni River channels follow fault zones in the northern part of the watershed.

Southern Afghanistan contains a mixture of intense desert, large mountain ranges, and river valleys. Kandahar City is situated in a relatively flat basin between the Arghandab River to the west and Tarnac River to the east. The city is bound on the north by high mountains and on the south by the Registan Desert. In this area where mountains transition into flatland there are several distinct ridgelines in the vicinity of Kandahar City. Within the city the topography gently slopes downward from north to south.

3.2 Climate

Commonly described as arid and semi-arid, water resources are scarce throughout the country and particularly in the south. Annual precipitation and elevation generally increase from south to north. Annual flows in rivers are most dependent on snow melt and rain in the mountainous highlands. Temperatures in Kandahar Province range from around 40 ºC in July to 0 ºC in January. Due to the location of the study area in relation to the surrounding mountainous areas, it is very uncommon for appreciable amounts of precipitation to fall within and around Kandahar City itself. In fact, this area can be classified as "hyper arid" (Whitney, 2006). For reference, "arid" lands have a precipitation to evapotranspiration (P/ET_P) ratio in between 0.2 and 0.03 while "hyper arid" lands have a P/ET_P ratio less than 0.03.

The most recent drought experienced in Afghanistan from roughly 2000 – 2003 resulted in environmental degradation and economic loss within Kandahar Province. The Arghandab, Arghistan, and Tarnac Rivers and their associated system of canals reportedly dried up for several years during the severe drought

(JICA, 2003). Coupled with an increase in IDPs and refugees, mitigating the effects of droughts in this region will be critical to the reconstruction effort. A sustainable water resource management strategy in such an arid climate receiving minimal rainfall becomes even more challenging with accelerated population growth.

3.3 Precipitation

As stated in Table 5, average precipitation in Kandahar City is lowest during the months of June – October, and during the recent severe drought reportedly no precipitation was observed for extended periods of time. Precipitation averages from 75 mm per year in the southern plains to 1,170 mm in the mountains (Aini, 2007). Precipitation within the area of interest can vary in magnitude, time, and form. This is due to several factors including dominant wind direction, air movement, and large elevation changes.

Dominant wind direction and air movement:
Wind direction, throughout most of the year, is from the north and west and blows to the south and east. Large air movements are not present during the summer and winter seasons (Farve & Kamal, 2004). Cold air from the Mediterranean can pass through Afghanistan in the winter along with monsoonal rains that travel from the Indian sub-continent in the late summer. In combination, these two meteorological patterns allow a small portion of the eastern part of the country to experience two rainfall peaks throughout the year.

Large elevation changes:
The Hindu Kush mountain range traverses through the central part and perimeter of Afghanistan. This results in the majority of precipitation falling on the windward side (north and west) of these mountain chains due to orographic effects. Additionally, the majority of precipitation that falls in higher elevations consists of snow. As this snow melts, river flows increase and allow for extensive irrigation downstream. Storage of water in the form of snow at elevations greater than 2,000 m represents approximately 80% of Afghanistan's surface water resources (Farve & Kamal, 2004).

Precipitation peaks in the spring during the months of March and April, as shown in Table 5.

Table 5. Monthly Average Precipitation (mm)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.	Year
Kandahar City	46.9	68.8	91.7	96.8	29.4	3.7	5.7	0.7	3.3	4.8	19.7	20.6	32.7	392

Source: Yuma Engineering & Saxe Engineering, 2009

3.4 Drainage Basins

The watersheds in the study area include the Upper and Lower Arghandab, Tarnac, Arghistan, Dori, Ghazni, Nahara, Jilga, and the Ab-i-Istada Lake depicted in Figure 5. The Registan Desert is located in southern Kandahar and does not contribute any runoff. The majority of the overland flow passes through the Arghandab River, which is fed mostly by snowmelt in the high-altitude tributaries in Zabul and Ghazni. Peak flows in the Arghandab River typically occur in March when snow upstream in the high mountains of Ghazni and Zabul melts. Peak flows in the other watersheds are also fed by snowmelt but typically occur during the months of January and February, earlier than the Arghandab River, which corresponds to higher temperatures in lower altitudes.

The Arghistan watershed includes the Arghistan Rod, Dori, and Lora Rod Rivers. Eventually, the Tarnac Rod and Arghistan Rivers flow into the Arghandab River and finally the Helmand River near Qala-i-Bost. From here, the Helmand River flows into the Sistan wetlands, which lie on the border of Afghanistan and Iran. Elevations of these watersheds range from over 4,500 m in the tall mountains in northern Zabul and Ghazni Provinces in the Upper Arghandab basin to about 750 m in the flatlands of the Lower Arghandab basin near the confluence with the Helmand River. The watersheds south of the Arghandab Basin see a second and smaller peak in the summer months, possibly part of a monsoonal effect.

The Arghandab watershed is split into the Upper Arghandab and the Lower Arghandab watersheds. The Upper Arghandab drains water upstream of Dahla Dam. The headwaters begin on the southern slopes of Dasht-I Nawur of the Ghazni Province. The Arghandab River flows from Ghazni southwest through the Arghandab and Mizan Districts of the Zabul Province before reaching the Dahla Dam in the Shah Wali Kot District of the Kandahar Province. Land area within the Upper Arghandab includes rangeland (74%), bare soil (19%), and irrigated land (6%). Approximately half of the irrigated land is intermittently cultivated, most likely due to water shortage and salt build-up within the soil.

The Lower Arghandab watershed is defined by the irrigated lands below Dahla Dam. This area extends from downstream of the dam to where the Arghandab River meets the Helmand River, near Qala-i-Bost. There are two main irrigation service canals, which are part of the Arghandab Irrigation Project (AIP) that originate near Dahla Dam. These canals irrigate crops, orchards and vineyards located around Kandahar City. Land area of the Lower Arghandab is dominated by bare soil (65%) and irrigated lands (15%). About 83% of the irrigated area is intermittently cultivated due to climatic conditions, management strategies at Dahla Dam, and deteriorating/incomplete infrastructure and sediment deposition at Dahla Dam. During times of drought, vineyards and orchards in the Kandahar City area are supplemented with irrigation water from deep wells. This practice has lowered the water table in the area, and now many of these deep wells can no longer be used.

The Ghazni, Nahara, and Jilga watersheds are separated from the Arghandab watershed by the ephemeral Ab-i-Istada Lake. However, this lake can overflow and spill into the upper parts of the Lora Rod River. However, this is an extremely rare occurrence. Even though these watersheds aren‘t perennially connected to the Lora River, groundwater flow between the various watersheds in the study area does occur.

These watersheds are fed from precipitation which falls in Ghazni, Vardak, Paktia, and Paktika provinces. Elevations within these drainage basins range from 1,950 to over 4,500 m. All together, these watersheds contribute over 17,000 km^2 to the already substantial study area. The study area comprises the majority of the Arghandab River basin, which is approximately 70,000 km$^{2.}$

The watersheds within the study area were based upon a SRTM / USGS 90m Digital Elevation Model. Extensions within ArcGIS, HEC-GeoHMS and ArcHydro, were used to automatically delineate the drainage basins.

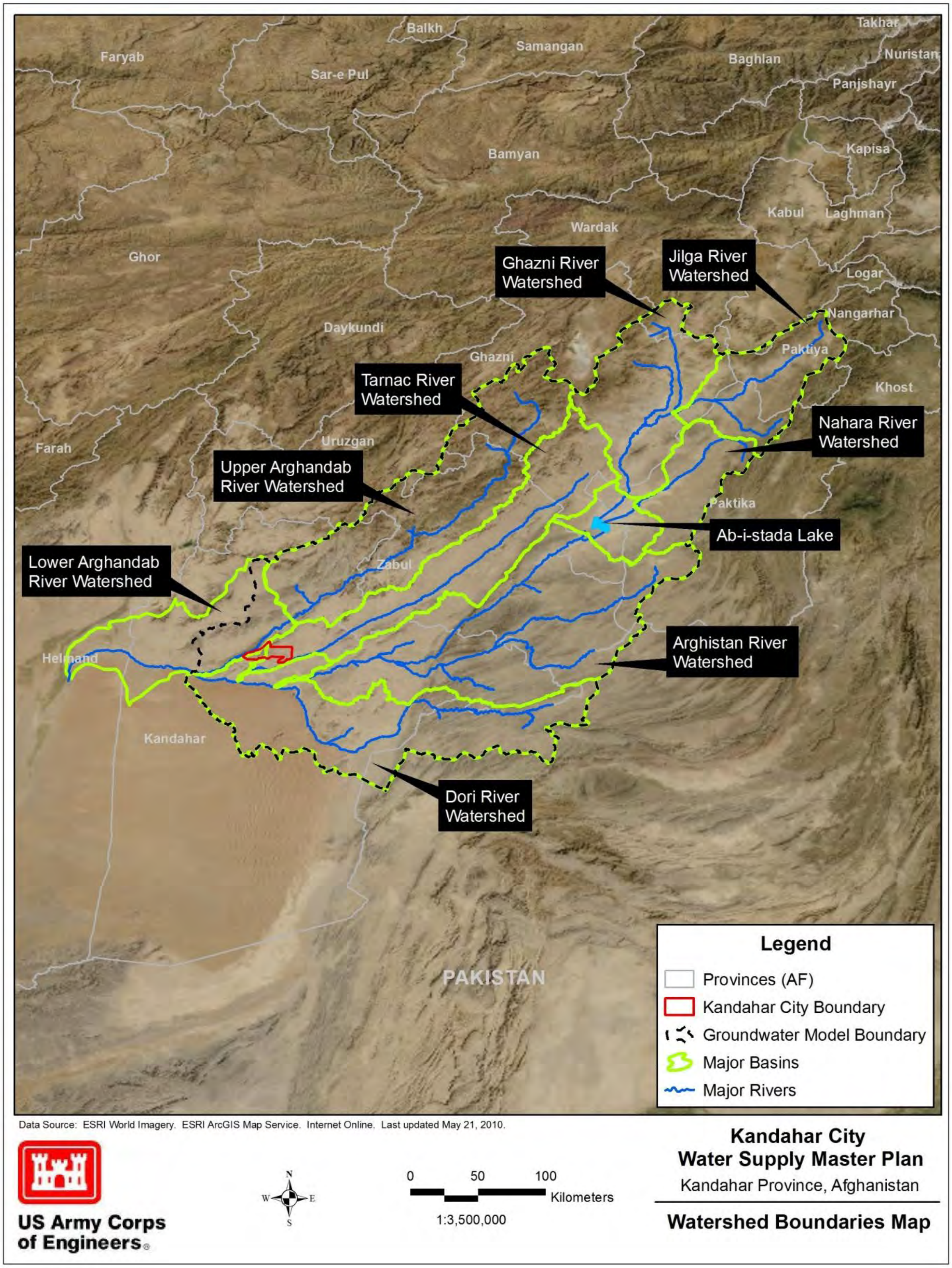


Figure 5. Watershed Boundaries

3.5 Regional Hydrogeologic Setting

A significant component of this Master Plan involves characterizing the existing conditions of the regional groundwater resources to assess whether a potential sustainable source of groundwater supply is present. To achieve this, the study team completed an inventory and review of available data and prepared a detailed groundwater model. The purpose of this analysis was to identify the presence or absence of a sustainable groundwater supply, and develop an understanding of the occurrence and movement of groundwater from recharge areas to discharge areas under natural and pumped conditions (existing and future). This addresses an objective of the Master Plan to determine regional groundwater conditions and the ability of the deep and shallow aquifers to sustain residents of Kandahar City in the near-term and long-term. In addition to identifying existing hydrogeologic conditions, the effort identifies problems and opportunities associated with groundwater development.

To accomplish this evaluation, the following tasks were completed:

- Developed a Conceptual Site Model (CSM) to spatially relate geology, hydrogeology, recharge areas and water levels to discharge areas both natural and man-made.
- Developed a 3-D groundwater flow model based on the CSM to estimate where groundwater is available and in what quantities.
- Using this information, estimated the locations, number of wells and producing aquifers to supply estimated and future water supply needs for Kandahar City.
- Estimated the mix between aquifer utilization, shallow and deep, to meet demand.
- Estimated the change to existing groundwater conditions based on implementation of proposed extraction schemes.
- Determined the viability of proposed changes. This will drive sustainability.

3.5.1 Prior Studies and Reports

Various sources of hydrometeorological data in and around the modeling area were found throughout this modeling effort. Appendix B shows the locations of the most pertinent hydrometeorological stations and sources that were available and used in this assessment including the Groundwater Evaluation Report, figures, and tables not included in the Master Plan.

3.5.2 Geology and Tectonic Setting

The study area's bedrock units have been divided along the Chaman Fault into the Helmand-Arghandab Uplift (west) and Alpine Fold Region (east) (Abdullah & Chmyroiv, 2008). The Helmand-Arghandab Uplift contains the pre-Cambrian and Paleozoic rocks belonging to the Afghan microplate and the carbonate-ultramafic rocks resulting from the Afghan-Indian plate collision. In contrast, the Alpine Fold Region east of the Chaman Fault Zone contains fewer carbonate units.

The abbreviated tectonic history presented here is taken from Whitney (2006) unless otherwise referenced. The Helmand Basin is a large, structurally closed basin that began to form during the middle Tertiary because of the collision of several former Gondwanaland fragments. Paleomagnetic studies in Afghanistan indicate that at least two, but probably more, continental fragments (referred to as microcontinents or microplates) broke away from the supercontinent Gondwanaland sometime during the Late Permian. These microcontinents drifted northward toward their present positions while rotating in a counterclockwise motion that is characteristic of Gondwanaland fragments. Collision of the Afghan microplate with the Eurasian continent, also called the Russian plate, was complete by Early Cretaceous, forming part of the northern boundary of the Helmand Basin. Remnants of ocean floor and plate margins are exposed along complex suture zones near Kandahar and Farah in ophiolite/ultramafic complexes interlayered in Cretaceous limestone. A more detailed description of the tectonic history can be found in Whitney (2006).

3.5.3 Regional Aquifers

In and near Kandahar, water-producing units within the basin sediments have been named (CDM, 2003). From bottom to top they include the City Aquifer, the Upper Confined Aquifer, and the Unconfined Aquifer. Aquifers in the study area and various associated physical properties are identified in Table 6.

Water-producing sediments below the City Aquifer were also identified from recent drilling (source of information) and have been named the Deep Aquifer for this study. The named aquifers are separated by thick (several tens of meters) confining layers of silt and clay. The continuity of the named aquifers within and beyond the Kandahar City area is not known.

Surficial materials include sands and gravels in alluvium along rivers, talus on mountain slopes, loess (a wind-blown deposit), and desert sands in the Registan Desert at the south end of the study area. Surficial deposits are typically less than 10 m thick except for the sands of the Registan Desert where thicknesses may reach several tens of meters. Where saturated, the surficial materials form the unconfined aquifer.
The unconfined aquifer is also known as the shallow aquifer. The upper confined and city aquifers are also known as the upper aquifers. The city aquifer system has potential as a source of groundwater supply. Cross contamination occurring with overlying aquifers in some locations means the water quality is brackish in these areas. Treatment and storage options would need to be assessed. The deep aquifer is significant to the Master Plan because it represents a potentially sustainable source of water and is the focus of the modeling efforts presented later.

Soils in areas of bedrock outcrops are generally thin, but include several meters of loess in some areas. Caliche formed by the near-surface leaching and precipitation of calcium carbonate in soils is present in some areas. Further information on the aquifers is available in Appendix B.

Table 6. Assigned hydrogeologic unit names for this study, correlative units used by others, and salient notes

Kandahar City Groundwater Model	Afghanistan Geological Survey (Abdullah and Chmyroiv, 2008)	DACAAR Nationwide Monitoring Report (Saffi, 2007)	Kandahar Groundwater Resource Assessment (CDM, 2003)	Description	Notes
Unconfined/Semi-Confined	Recent, Aeolian+ Talus, Upper & Middle Quaternary	Unconfined	Unconfined	Gravels, sands, talus, sand loam	Loess cover present in north and much of Kandahar area
Upper Confined	Neogene	Neogene Multi Aquifer System	Upper Confined	Sands and gravels	May not be correlative with northern part of the model domain
City Aquifer	Neogene		City Aquifer	Sands and gravels with scattered layers of conglomerate and caliche	• Not correlative with northern part of the model domain. • Hard layers at percussion drilling limit (100-120 m) will give a false bedrock depth.
Deep Aquifer	Paleogene - Helmand-Arghandab Uplift	Not Defined	Not Defined	Variably cemented, red to pale red fine grain sediments with sandstone and conglomerate	• Not correlative with northern part of the model domain. • May be source of artesian flow.
Mixed Age Carbonate Bedrock Aquifer System	• Cretaceous Bedrock Aquifer System • Paleozoic Aquifer System	Fracture Karst Water	Not Defined	Carbonate units known and suspected to have karst potential	Relatively High Hydraulic Conductivity, enhanced near faults and major fracture zones
Mixed Age Coarse Clastic Bedrock Aquifer System	Not Defined	Not Defined	Not Defined	Cambrian-Cretaceous and younger sandstones and conglomerates, and some mixed carbonate units	Relatively Medium Hydraulic Conductivity Excluding Fracture Sets and Faults
Mixed Age Low Porosity Bedrock Aquifer System	• Paleogene Katawaz Artesian Basin • Mixed Age Intrusives Aquifer System • Pre-Cambrian Aquifer System	Not Defined	Bedrock	Igneous, metamorphic, and fine grained sedimentary rocks	Relatively Low Hydraulic Conductivity Excluding Fracture Sets and Faults

3.5.4 Hydraulic Conductivity

The hydrogeologic property of greatest significance in the groundwater model is the magnitude of hydraulic conductivity (K), which describes the permeability of the various aquifer systems and their relative ability or inability to allow groundwater flow under both natural and pumping conditions. The hydraulic conductivity for several hydrogeologic units was determined using pumping and drawdown data collected during well-yield and aquifer tests. Aquifer tests were conducted in and around the city of Kandahar and at Forward Operating Bases (FOBs) located within or near the Arghandab River watershed.

The calculated aquifer K values were developed at more than three dozen extraction wells located in the immediate vicinity of the city of Kandahar and in areas around the Arghandab River watershed. These values were used to derive ranges of K values for each of several aquifers and to provide a comparative dataset for use in model calibration. The evaluation of aquifer test data shows that the unconfined and upper confined aquifers have the highest hydraulic conductivity in the Arghandab aquifer system. The city aquifer has a conductivity value as much as two orders of magnitude lower than the overlying aquifers but is less susceptible to contamination than the upper aquifers and is therefore more desirable as a drinking water source. The measured hydraulic conductivity in the deep Paleogene aquifer system is an order of magnitude higher than the productive city aquifer and, provided that the supply of water to this aquifer is adequate, should provide a significant amount of groundwater with minimal drawdown. Full descriptions of the tests conducted, type of data available, collection methods, and evaluation of hydraulic conductivity can be found in Appendix B.

3.5.5 Recharge and Discharges

There were two primary sources of recharge considered to the groundwater system in question. These include:

- Surface infiltration of precipitation
- Leakage from surface water bodies
    - Rivers
    - Reservoirs
    - Canals

In addition to the sources of water to the groundwater system there are several sinks that allow groundwater to escape from the system. These include:

- Evaporation
- Transpiration
- Groundwater pumping
- Surface water bodies
- Groundwater movement (SW boundary)
- Karezes

Groundwater recharge is dominantly in mountainous areas where precipitation exceeds evapotranspiration. Conceptually, rivers and streams are mainly groundwater discharge areas and are not major sources of recharge for current pumping conditions but could become sources with a lowering of the water table by pumping. The Loy Walla Canal is a major potential source of groundwater in the Kandahar area (CDM, 2003). Leakage from other irrigation canals and infiltration of irrigation water applied to fields are other sources for groundwater. Groundwater discharges mainly to streams where much of the water is lost to evapotranspiration. The discharge of groundwater also occurs by pumping from numerous irrigation wells, domestic wells, and public-supply wells, mostly in the Kandahar City area. Numerous karezes in the study area shortcircuit groundwater through tunnels to the land surface.

3.6 Water Quality

3.6.1 Data Sources

Water quality data for the Kandahar area are limited. The U.S. Army Institute of Public Health provided groundwater chemistry data for wells located at 15 of the 18 FOBs within the Arghandab River basin (DOEHRS, 2011). There were a total of 76 suites of samples. The U.S. Military Preventive Medicine Units routinely collect water samples and submit them for extensive testing but a few analytes are excluded that are basic for depicting groundwater geochemistry – namely potassium, carbonate and bicarbonate.

CDM collected water samples and analyzed them when they were in Kandahar City on a USAID project (CDM, 2003). The Danish Committee for Aid to Afghan Refugees (DACAAR), an NGO, has also produced some water quality data over the years for Kandahar City but the data were not available.

A summary of published water quality by aquifer system is shown in Table 7.

Table 7. Summary of published regional water quality by aquifer system

Kandahar City Groundwater Model	Regional Hydrogeologic Unit	Geographic Region	Water Type(s)	TDS Range (mg/l)	Temp. Range (°C)
Unconfined-Semi Confined	Recent Alluvium Aquifer, Eolian, Talus Deposits, Terrace Deposits	Arghandab, Duri, Lura, Tarnac, and Argistan river valleys	Twenty different water types, with one or more present in each region	400 - 3,220	10 - 25
Upper Confined	Neogene Aquifer System (Sistan Basin)	Left bank of Helmand River	▪ chloride-sodium-calcium ▪ chloride-sodium	1370 - 3100	19 - 25
City Aquifer	Neogene	No Data	▪ No Data	No Data	No Data
Deep Aquifer	Paleogene Aquifer System-Helmand-Arghandab Uplift	Upper elevations	▪ bicarbonate and sulphate-bicarbonate-calcium ▪ sulphate-bicarbonate ▪ chloride-sulphatesodium ▪ sulphate-chloride-bicarbonate-calcium	300 - 1800	No Data

Bedrock-Relatively Low K	Pre-Cambrian, Paleogene Fresh and Mineral Aquifer Systems and mixed age Intrusive Rocks	Helmand-Arghandab Uplift and Katawaz Basin	▪ bicarbonate-calcium ▪ bicarbonate-magnesium-calcium ▪ bicarbonate-sodium-calcium ▪ chloride bicarbonate-sodium ▪ chloride-sulphate-sodium	300 - 2960	5 - 21
Bedrock-Relatively Moderate K	Paleozoic Aquifer System	Mostly Arghandab Watershed	▪ bicarbonate	100 - 700	5 - 16
Bedrock-Relatively High K	Cretaceous Aquifer System	Carbonates and fractured Cretaceous bedrock within the Tarnac structural basin, and locally in the Lura Rod and Duri Rod valleys, and west of the Mokur Fault	▪ chloride-bicarbonate-sulfate-sodium ▪ bicarbonate-chloride-sodium ▪ bicarbonate-sodium ▪ bicarbonate-sodium-calcium ▪ sulfate-chloride-sodium and chloride-sodium ▪ bicarbonate-sulphate-sodium (near fault zones)	300 - 2200 620 - 680 near fault zones	17 - 27

Source: Abdullah & Chmyroiv, 2008

3.6.2 Drinking Water

The two primary concerns for water quality throughout Afghanistan are bacterial contamination and high total dissolved solids. There are no results for bacterial contamination (i.e. *E. coli*) in the Defense Occupational and Environmental Health Readiness System (DOEHRS) database. Bacterial tests are run on a more frequent basis by the Preventive Medicine Units and are not part of the annual analyses. There are general patterns of groundwater quality in Afghanistan that have been documented for the Kabul area (Broshears, Akbari, Chornack, Mueller, & Ruddy, 2005). That study found a large number of biologically-contaminated wells, even deep ones, suggesting poor well-construction practices.

One of the important characteristics of water supply in Kandahar City is that water flows through the Loy Walla Canal and infiltrates into the shallow unconfined aquifer underlying Kandahar City. CDM (2003) found a trend of increasing total dissolved solids in shallow groundwater from west to east. Water has been flowing through canals in Kandahar City for hundreds of years and the downward flow of water has leached sediments in the unconfined aquifer and resulted in higher total dissolved solids with depth (Sammel, 1971). CDM tested several wells in Kandahar City and found that most had total dissolved solids around 1,000 mg/L. There are fine-grained confining layers at depths that retard downward flow.

Water in the unconfined aquifer undergoes recycling as residents pump the shallow groundwater, use it, then discharge it to ditches along the street, pit latrines, etc. The contaminated discharge infiltrates the subsurface to again recharge the shallow aquifers. The speed of recharge is unknown but in Kabul the USGS used isotopic age dating to determine that groundwater (from 35 wells and 6 springs) had a median apparent age of 21 years (Mack et al., 2009). This suggests a slow recharge from the surface sediments.

Sammel (1971) found that the groundwater in Kandahar City was of the sodium-chloride-sulfate type whereas surface water in the Arghandab River was predominantly calcium-bicarbonate water. The DOEHRS database reports calcium and magnesium and their combination indicates that the water in the

Kandahar City area is hard to very hard. The total dissolved solids (TDS) value is a general indicator of mineralization in the water. Indications are that the concentrations around Kandahar City can be greater than the international standard maximum of 1,000 mg/L TDS for drinking water. The well at FOB Walton in Kandahar City and the wells at Kandahar Air Field (KAF) have high TDS (1,500-2,200 mg/L range). However, a recent well at KAF (Seabee Deep South Well #1) was cased to a depth of approximately 400 m and reportedly was a flowing well with excellent water quality having low TDS.

Chloride (Cl), boron (B), sodium (Na), sodium adsorption ratio, and water hardness were also looked at from the perspective of water quality. One of the FOBs that stood out for high TDS, Na, Cl, and B was Spin Boldak. The explanation probably is similar to the situation at Kandahar City. The Spin Boldak FOB is in the Arghistan basin and the general area receives surface water from the nearby mountains that irrigates agricultural land. Following centuries of irrigation, the surface water has continued to leach the shallow sediments resulting in high total dissolved solids in the deeper groundwater.

Boron is commonly a toxic element for irrigation water, but is the one problematic elements that stands out for drinking water in Kandahar City. The World Health Organization (WHO) has raised the limits this year for boron from 0.5 mg/L to 2.4 mg/L (2011). There are wells in the Kandahar City that still exceed the limit.

3.6.3 Irrigation Water

Irrigation water is critical to the livelihoods of many residents in the Kandahar area and has been for centuries. Generally, surface water is used for irrigation but during droughts, residents have pumped groundwater to help them through the dry periods.

Commonly, the toxic elements for irrigation are chloride, sodium, and boron (Ayers & Westcot, 1985). Each of these elements was evaluated at the FOBs of the Arghandab Basin. The results indicate that groundwater under Kandahar City, KAF and Spin Boldak have such high chloride, sodium and boron as to be toxic to some plants. For example, grapes are a major agricultural product of Kandahar City with a raisin factory within the city. While grapes need boron, they are sensitive to it and higher concentrations (> 0.5 mg/L) can reduce the yield (Ayers & Westcot 1985). Of the groundwater tested, 50% had concentrations greater than 0.5 mg/L of boron.

3.6.4 Summary

Conclusions can be drawn on the water quality in the Kandahar area although they are based on limited data, inferences and expectations. The quality of water behind Dahla Dam is expected to be very good (< 350 mg/L TDS). Associated with that, the groundwater quality in the alluvium of the Arghandab River is expected to be good (< 500 mg/L TDS). As water from the Arghandab drainage has leached through the sediments of the unconfined aquifer at Kandahar City, the result has been groundwater quality in the upper confined/city aquifer that is marginal (~1000 mg/L TDS). There are problems with this water for irrigation purposes. The groundwater in the Ant Valley area is expected to be of very good quality. Finally, the groundwater of the deep aquifers is anticipated to be of very good quality. More data collection is needed in order to confirm these expectations.

3.7 Regional Surface Water Use and Management

In order to improve the water supply situation in Kandahar City, it is critical to understand how water resources in the region are utilized, managed, and the effects of development on the resource.

Information on water resource management development in the study area is described below and provides context for understanding many of the water resource problems facing the Kandahar Province and Kandahar City.

Kandahar Province derives some benefits from water resource projects constructed for irrigation and water supply. Dahla Dam was constructed originally as a multi-purpose project in the mid-twentieth century. The reservoir is a significant source of irrigation in the Lower Arghandab watershed. Water released from the dam is diverted into a system of primary canals which feeds smaller canals that make their way to the farm fields in the area around Kandahar City. Along with these primary benefits, some residents of Kandahar have utilized water from the nearby Loy Walla Canal as a source of drinking water despite poor water quality and lack of treatment. Groundwater is mostly used for domestic purposes in and around Kandahar City but also for irrigation, and increases in the latter were observed during the recent severe drought.

3.7.1 Irrigation Systems

The Arghandab River is the primary source of water for a network of irrigation canals that make up the AIP. The system of earthen canals serves as an irrigation source for farmland in the Lower Arghandab watershed below and served by the Dahla Dam reservoir. According to the CIDA (2008) the project is composed of five main canal systems, including the North Branch, South Branch, Tarnac Canal, Babawali Waste Way, and the South Canal. Water is typically drawn into these canals from the Arghandab River at the Arghandab Headworks then conveyed through a system of secondary and tertiary canals before reaching farm fields. The canals do not contain a lining, allowing for water loss through infiltration which recharges groundwater levels along the canal system. Recent estimates by USACE consider the canals in this area are 40% efficient, previous studies have used 25%. Information on the existing canal network was derived from prior reports. Despite being unable to conduct site visits during the study period, the CIDA (2008) report has good information on the existing canal network. Based on that report, the existing canal network is very inefficient due to ―high conveyance loss in the delivery system, lack of well-designed gated control structures, and high on-farm water losses caused by over-irrigation, mismanagement of the irrigation water, and poorly leveled land."

Farming is critical to the economy and livelihood of the population in the Arghandab Valley. According to information retrieved from CIDA (2008), irrigators require water from the Arghandab system from April to November with peak demand occurring in July and August. Irrigation demands in the project area have been estimated to be around 800 million m^3 / year (CIDA, 2008), which assumes a specific cropping pattern, area, efficiency, average weather, etc. Actual demands in a given year vary depending on the type and quantity of crops planted, conditions of the canals, irrigation practices, weather patterns for that year, and other factors. The reservoir itself suffers from deficiencies and is vulnerable to drought, but has generally provided a dependable source of water for local farmers.

Water supply from the AIP benefits crops and livestock which generate income and a source of food for the region. Because of the sense of water security within the farming community, canal maintenance and removal of sediment has been neglected over time, further reducing inefficiency of the system. During droughts in 1971 and from 1998 – 2003 the irrigation system was unable to meet demand. As a result, groundwater development for irrigation increased stress on the water table which in some cases resulted in complete abandonment of farmland (CIDA, 2008). In Kandahar City, it is common for some residents without access to piped water to get domestic water supplies directly from the Loy Walla Canal, and when the canal dried up, an increase in domestic groundwater wells also occurred which impacted the water table in the shallow aquifers.

3.7.2 Dahla Dam

Originally called the Arghandab Dam, Dahla Dam is situated on the Arghandab River approximately 34 kilometers northeast of Kandahar City. The dam was constructed from 1949 to 1953 with funding from the USAID and the GIRoA and construction oversight from the United States Bureau of Reclamation (USBOR). Original purposes of the dam included flood control, irrigation, and hydroelectric power. Following construction of the dam, the hydroelectric components were never installed and since then the most significant contribution of the project has been as a source of irrigation to the AIP.

Sedimentation is one of the most significant problems to overcome and has caused an estimated 30% loss in storage volume (CIDA, 2008). Preliminary sediment models by the USACE (2011) approximate future reservoir capacity losses due to sedimentation to be: 34% in 2015, 51% in 2035, and 72% in 2065. The primary reasons for sedimentation in the reservoir are thought to be high rates of erosion upstream caused by lack of adequate erosion control management practices, overgrazing, deforestation, reoccurring drought cycles, and inadequate soil management techniques (CIDA, 2008). Erosion rates are thought to be increasing as well. Storage loss increases water shortage problems for downstream farmers and others who depend on water from canals, which are filled at the Arghandab Headworks downstream from the reservoir.

Capacity of the reservoir is limited by the size of the dam, and decreases in storage volume. Over the history of the dam, spillage has been reported as a regular occurrence, indicating that the system is not capturing all the potential storage benefits. During the spring irrigation season water is released from the dam until the water level drops below the outflow gate. Storage is then captured as rain and snowmelt fill the dam over the winter and spring. Additional storage is desirable from a municipal and industrial perspective and could also serve to supplement deficient irrigation supplies. Operation practices would require modification if water was allocated for municipal purposes. CIDA (2008) stated that the water supplies from the dam are inadequate and failing to meet the irrigation demand of all downstream users. In addition to water shortages, this is probably partially due to poor timing of releases, inefficiencies with releases at the Arghandab Headworks, and poor agricultural and water conservation practices downstream.

3.7.3 Water Mass Balance at Dahla Dam

The feasibility of using water from Dahla Dam for human consumption needs to be analyzed in depth. A simplified model is provided in Figure 6 and it depicts the different river water use components, which includes a proposed municipal water supply. In general, whether water from the reservoir can be drawn for human consumption or not, will be determined by the availability of water for irrigation downstream in addition to losses (evaporation and infiltration into the ground). The basic assumption for the simplified analysis is that the minimum average inflow to the dam (Q_{inflow}) should sustain the water supply demand (Q_{ws}) plus the demand for irrigation ($Q_{irrigation}$) plus losses for infiltration and evaporation (Q_{losses}).

In general, $Q_{inflow} – Q_{losses}$ (at dam) $– Q_{ws} = Q_{irrigation} + Q_{losses}$ (along canal) $+ Q_{outflow}$

Based on recent hydrological and meteorological studies conducted by the CIDA (2008), and based on historical data available, the flow of the river is seasonal in nature, which indicates a drastic fluctuation throughout a calendar year. Median and average monthly flows in the Arghandab River are shown in

Table 8. USACE estimates indicate that roughly 10% of the existing storage capacity of Dahla Dam would be able to meet the demand of the existing population at 120 lpcd.

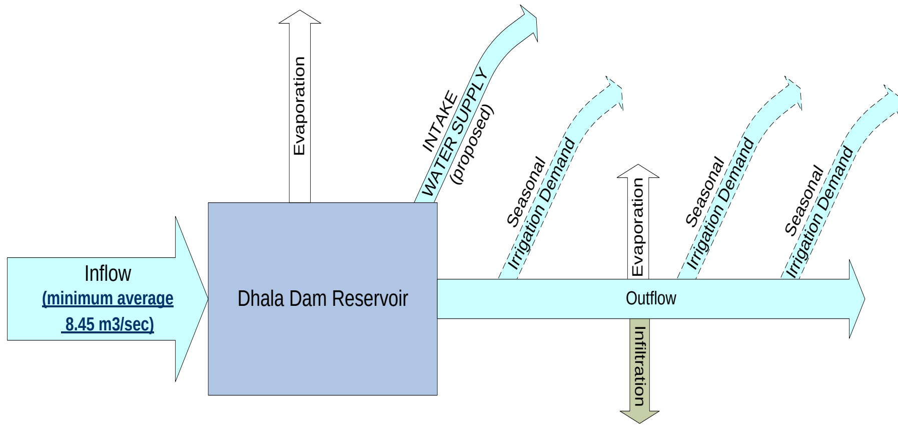


Figure 6. Simplified Model for Water Mass Balance at Dahla Dam

Table 8. Maximum, Minimum, Median and Average of the Monthly Flow of Arghandab River (m3/sec)*

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Maximum	18.7	41.8	59.1	57.3	82.8	204.0	333.0	229.0	86.4	104.0	28.7	19.8
Minimum	1.1	6.9	7.9	13.0	12.7	20.4	13.7	3.0	0.5	0.0	0.1	0.5
Median	10.3	16.3	19.5	20.6	38.3	73.8	115.0	66.3	21.6	16.4	10.5	6.9
Average	11.0	17.5	22.3	24.3	40.6	90.2	139.7	83.5	27.6	23.3	11.2	8.5

*Based on 27-Year Record on the Data from the Gauging Station above Dahla Dam

3.7.4 Operation and Maintenance

The Ministry of Energy and Water is responsible for the development and management of water resources and related infrastructure, including diversion canals. The Helmand Valley Authority used to manage, maintain, and operate the Dahla Dam reservoir and canals in Kandahar Province but reportedly no longer has trained staff or the authority (CIDA, 2008). Releases from Dahla Dam into the primary system of canals are controlled by staff from the Kandahar Provincial Water and Irrigation Department in Kandahar City. Secondary and tertiary canals are operated and maintained by the farmers using water from the canals. In downstream communities and villages, the Mirabs control water distribution and maintenance. Mirabs are either appointed or elected and have the ability to call on members of the community to repair the canal system.

3.8 Climate Change

The *Kandahar Drinking Water and Sanitation Report* (Yuma Engineering & Saxe Engineering, 2009) comments on climate change in relation to Kandahar. Low winter precipitation occurs in two consecutive years once every fifteen years based on historical records available. Glaciers in the highest elevations decreased in size following the last drought cycle, which could be attributed to climate change. Regular fluctuation in snowmelt combined with loss of glaciers in the mountains could significantly impact water supply in Kandahar City and the region if it increases the severity, frequency, or length of droughts.

More extreme weather patterns will increase risk and vulnerability of ‗at-risk' groups such as Kuchis and IDPs, thus more research needs to be done on understanding impacts of climate variability upon water resources. According to a study for the United Kingdom Department for International Development (DFID) (Savage, Dougherty, Hamza, Butterfield, & Bharwani, 2009), the worsening climatic conditions as predicted by global climate models will create stress for these vulnerable groups and sectors. Models suggest that Afghanistan could be afflicted by drought, desertification and land degradation, which may become ‗new norms.'

3.9 Summary of Water Resource Findings

Research of available information, technical analysis, and consultation with Afghanistan government officials and international representatives has revealed the following findings:

- The two primary sources of recharge to the groundwater system are surface infiltration of precipitation and leakage from surface water bodies.
- The evaluation of aquifer test data shows that the unconfined and upper confined aquifers have the highest hydraulic conductivity in the Arghandab aquifer system.
- The deep aquifer system has potential as a source of groundwater supply. Water quality is currently not known but assumed to be of better quality than overlying aquifer systems.
- Surface water supply in Kandahar Province is driven primarily by precipitation and snowmelt in the upper portions of the watersheds north of Kandahar City.
- Early indication is that Dahla Dam could be a potential source of water supply for the city.
- Preliminary sediment models by the USACE approximate future reservoir capacity losses due to sedimentation to be: 34% in 2015, 51% in 2035, and 72% in 2065.
- During years of drought, the Dahla Dam reservoir does not have the capacity or management scheme in place to meet downstream irrigation demand.
- Afghanistan's government currently does not have a water management plan in place to manage the reservoir, irrigation canals, or development of groundwater resources as an integrated system.
- Surface water and groundwater quality is generally unknown, but the deep aquifer is thought to be relatively clean.
- Better awareness of climate vulnerability and more climate resilient infrastructure are needed.

4.0 EXISTING WATER SUPPLY INFRASTRUCTURE

4.1 Existing Conditions

This section discusses the current water supply situation in Kandahar City. Information presented in the section was obtained from a combination of existing documents and information obtained from AUWSSC, ICRC, and UN-HABITAT through USACE AED-S in March 2011.

4.1.1 Production Wells

The current status of the 15 production wells in Kandahar City is shown in Table 9 and locations of all wells are shown in Figure 7. Only nine out of 15 wells are reported as operational. The potential combined maximum water production is close to 300 l/s. Assuming an operational cycle of 20 hours a day and all wells working normally, the current maximum production capacity is estimated to be approximately 20,000 m^3/day (981 m^3/hr). Based on preliminary USACE findings the maximum sustainable yield of the upper and shallow aquifers in Kandahar City is around 10,000 m^3/day. The potential production is far from the current reality due to well operation currently being limited by a reliable supply of electrical power to run pumps.

Table 9. Existing Production Wells in Kandahar City

USACE AED-S Identifier	Well Name	Other Well Names	Well Yield/ Discharge (gpm)[1]	Dynamic Water Level (m)[2]	Well Status
1	**Mechanic School**	Well 1, Mechanic College, Mech Lycee	491	21	Well in operation when 2010 rehabilitation completed.
2	**East of CAWSS**	Well 2, East of AUWSSC	475	14.5	Well in operation when 2010 rehabilitation completed. Supplying water to a reservoir as of 2002.
3	**South of CAWSS, No 1**	Well 3, South of AUWSSC, No 1	254	11.6	Well in operation when 2010 rehabilitation completed
4	**Fazal Kandari School**	Well 4, Faisal Kandahar Elementary School	872	15	Well in operation when 2010 rehabilitation completed
5	**Small Reservoir**	Well 5, Near Small Reservoir	507	17	Not Operational- to be connected to the generator soon by ICRC and HABITAT.
6	**Old Eid Gah**	Well 6, Eid Gah, Eid Gah Mosque	-	-	Not Operational- to be connected to the generator soon by ICRC and HABITAT
7	**Power Station Compound**	Well 7	270	-	Operational (low yield) Private use
8	**ARCS Clinic Compound**	Afghan Red Crescent Society Clinic Compound, Well 8	396	31	Well in operation when 2010 rehabilitation completed
9	**Commando Compound**	Well 9	222	-	Broken
10	**Mir Wais Lycee**	Mirwaise High School, PW12, Meer Ways Nika High School, Well 10	333	24	Well in operation when 2010 rehabilitation completed
11	**South of CAWSS, No 2**	South of CAWSS, Well 11, South of AUWSSC No 2, Well 11	443	23	Well in operation when 2010 rehabilitation completed. Well house needs unspecified repairs.

11a	**Ahmad Shah Baba Lycee**	PW11, South of CAWSS No 2/AUWSSC No 2, Well 11.	-	-	Not Known - Unconfirmed report indicates well is broken
12	**Mah Bas Prison**	PW13, Sarposa Prison, Near Prison, Well 12	475	31	Well in operation when 2010 rehabilitation completed
13	**Mirza Mohmmed Qalacha**	Mirza Mohammad Kalacheh, Well 13	254	-	Broken
14	**Quli Urdu No 1**	Well 14	317	-	Not Operational when 2010 rehabilitation was attempted (working in 2002).
15	**Quli Urdu No 2**	Well 15	349	-	Not Operational when 2010 rehabilitation was attempted (working in 2002).
	CAWSS TW1	May also be called AUWSSC TW1	-	-	Not Known
	CAWSS TW2	May also be called AUWSSC TW2	-	-	Not Known
	Sadat Ghundai	TW3	-	-	Not Known
	Lowi Walla TW4	TW4, Lo Walla	-	-	Not Known
	Aino Primary School	Ayno Primary School	159	36	Well in operation when 2010 rehabilitation completed
	Municipal Artesian Well	Well 44 (historic), current name is not known.	-	-	Not Known

[1] Unclear if values are from 24+ hour well test, or pump specifications.
[2] Based on areas with no water production, health, and education. Does not reflect other initiatives.

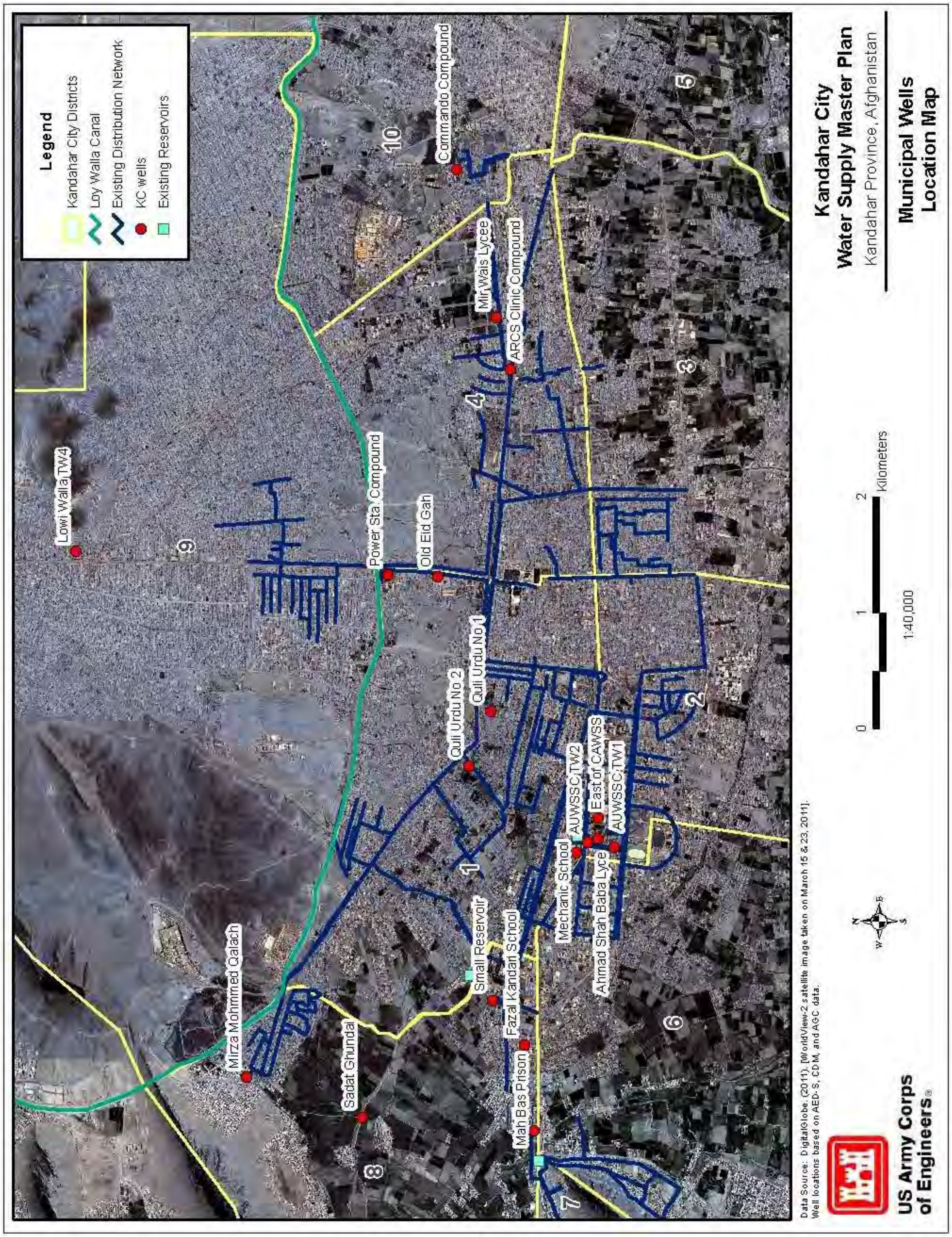


Figure 7. Municipal Wells in Kandahar City

4.1.2 Private Wells

In Kandahar City, those without access to water from the distribution network get water from privately dug wells or directly from the Loy Walla Canal. It has been estimated that over 356 private hand tube wells were installed for households in Kandahar City by United Nations International Children's Emergency Fund (UNICEF), UN-HABITAT, German Agro Action (GAA), DACAAR, Oxford Committee for Famine Relief (OXFAM), and other NGOs. Drilling is not regulated which presents concerns over contamination and over-extraction. The Ministry of Mines has raised concerns with this as well as licensing before (Yuma Engineering & Saxe Engineering, 2009). It is suspected that contamination in the shallow aquifer occurs by surface infiltration. The contamination of the shallow aquifer is compounded by the lack of a proper wastewater collection and treatment system and the proliferation of private septic tanks and privately-owned wells.

The use of private wells may be considered a ―relief" to the acute water problem in the city, but in reality, the uncontrolled tapping into the existing aquifers results in health and safety hazards. First, the quality of the groundwater is not controlled and potentially hazardous and not suitable for human consumption. Secondly, the multiple holes in the ground are conduits for cross contamination of the aquifers. The proliferation of private wells creates a long-term health and safety problem.

4.1.3 Water Storage

Kandahar City's water distribution system has two reservoirs of 1,000 m^3-capacity, each located at the AUWSSC yard and a recently constructed storage reservoir with a 400 m^3-capacity located at the southern end of the gap in western Kandahar. The latter is the Sarpoza Reservoir (see Figure 8). A fourth reservoir has been identified near the hospital in western Kandahar City. The smaller reservoir is located at the north end of the Mir Bazaar and Old City neighborhoods and likely has a connection to a functioning well located just to the east. These provide the only water storage on the distribution system.

Source: International Committee for the Red Cross (ICRC), 2011

Figure 8. Sarpoza Reservoir

4.1.4 Water Quality and Treatment

For the purpose of this report, water quality data, focusing on total dissolved solids data was the principal chemical indicator to determine water quality. The WHO (2003) indicates that ―Water containing TDS concentrations below 1,000 mg/L is usually acceptable to consumer, although acceptability may vary according to circumstances." As is discussed further in Appendix B, of the 272 water quality records that were evaluated as part of this assessment, only one sample contained TDS above 10,000 mg/L. For a summary of TDS ranges by aquifer see Table 7 and for additional information on drinking water quality see Section 3.6.2 or Appendix B.

No treatment is provided at any of the existing well locations in the city. Untreated brackish well water is pumped directly to the distribution network exposing the population to biological contaminates. Chlorination at AUWSSC headquarters (wells 1, 2 and 3, 11) is possible but has not occurred within the last two years due to inadequate resources. The water treatment process was manual mixing of bleaching powder with water in a bucket and dropping doses into water entering the reservoir. This quantity was not measured and only performed periodically. Chlorination of groundwater may be enough to prevent contamination in the distribution network but if mixed with non-chlorinated raw water from other sources, the potential for spreading waterborne diseases increases due to dilution of the active agent.

4.1.5 Water Distribution Network

The existing water supply network is shown in Figure 9 and was developed using the information available to the USACE PDT. Water supply studies in the last 10 years have reported on or conducted reconnaissance on the existing system resulting in varying degrees of documentation. The current master planning effort by USACE is constrained by time, making a site visit to inspect existing infrastructure impractical. Concerns with security and the logistics of inspecting the entire system are also difficult to overcome. Kandahar City's water supply network has many deficiencies due to poor maintenance and decades of war. The existing system was initially constructed in 1972 and subsequently expanded to meet demand as the city grew (JICA, 2003). Decades of conflict have stifled substantial efforts to improve, maintain, and expand the system. In 2008, CIDA estimated that the existing network served 30% of the city's population, but this Master Plan estimates that further degradation has occurred due to the non-functioning wells and only 20% of the city is currently served.

Water distribution network statistics were obtained from the Central Authority for Water Supply and Sewerage (CAWSS) for the Belleret al. study (2005) because at that time CAWSS was responsible for management and maintenance of related infrastructure. Since then, the AUWSSC has taken on the responsibility of operation and maintenance of Afghanistan's urban water supply systems. According to the statistics presented by Belleret al. in 2005, the total length of pipelines in Kandahar City was 115.3 km made up of four types of materials as shown in Table 10. Piping diameter and material were checked through selective excavation. The condition of asbestos cement pipes was mostly good while polyvinylchloride (PVC) and polyethylene (PE) pipes were found to be low quality. Galvanized steel (GS) pipes were clogged and corroded (Belleret al., 2005).

Table 10. Existing Pipeline by Material

Material	Percentage
Asbestos-cement (AC)	65%
Polyvinylchloride (PVC)	22%
Polyethylene (PE)	10%
Galvanized steel (GS)	3%

Source: Beller et al., 2005

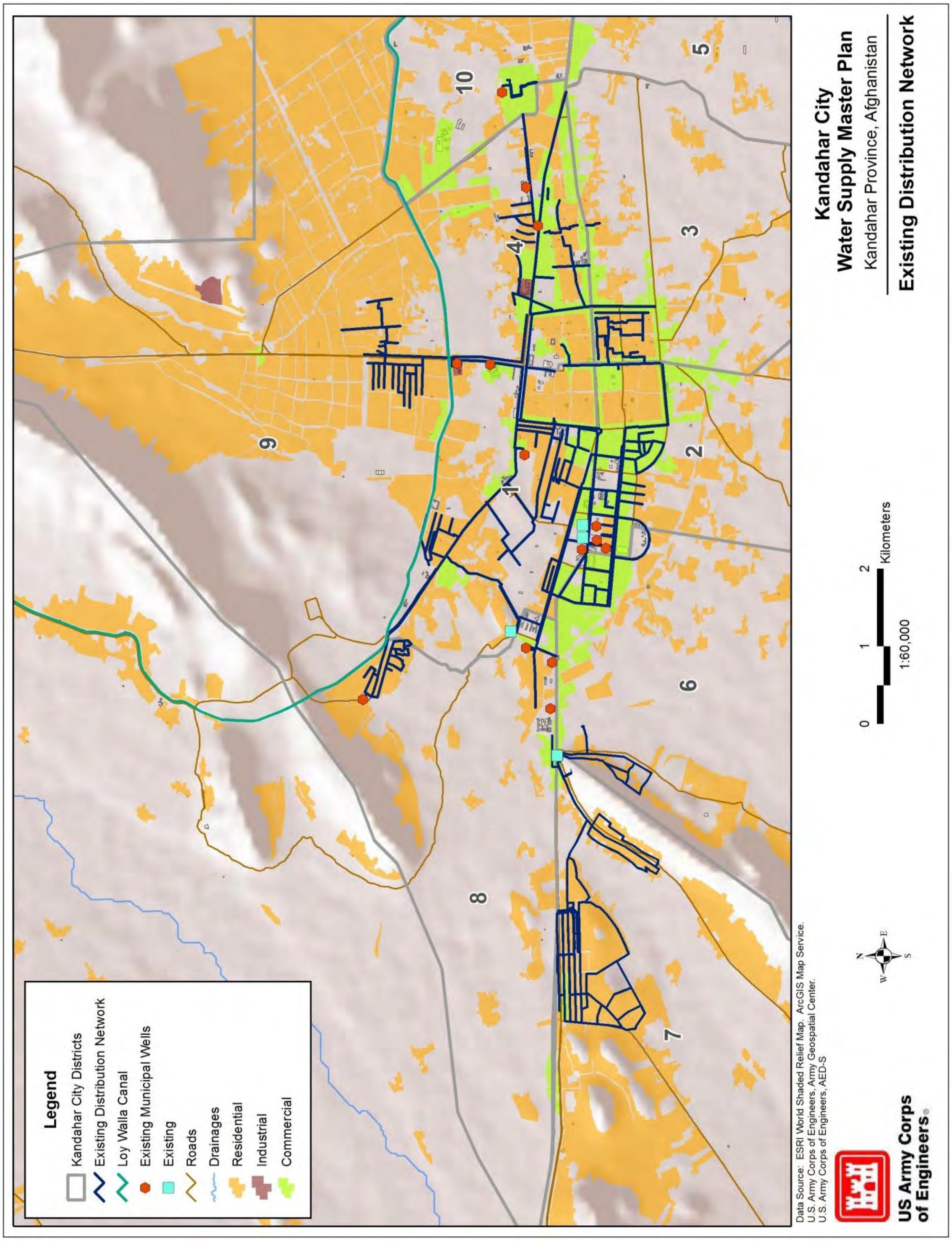


Figure 9. Existing Water Supply System

The existing water distribution system consists of pipe sized from 40-300 mm and approximate lineal meters of each size are listed in Table 11. Additional pipe that is not connected to the distribution network and pipe that is smaller than 40 mm is not included in this table. Approximate lineal meters of each size are listed below. Information about the recipients of water supply services was also available in the Beller report and is provided in Table 12.

Table 11. Existing Pipe Length by Size

Connection Size (mm)	Length (m)
300	3,732
250	2,342
200	6,786
150	22,049
125	2,000
110	5,023
100	11,201
90	664
80	17,731
75	4,264
63	1,329
50	4,091
40	1,200

Table 12. Customers Served by Existing Distribution Network

Connection Size	Domestic Connection	Govt. Office Connection	Commercial Connection	Holy Places Connection	Total
6.4 mm (1/4 inch)	29	24			53
12.7 mm (1/2 inch)	114	19	4		137
19.1 mm (3/4 inch)	1,520	42	45	3	1,610
Totals	1,663	85	49	3	1,800

Source: Beller et al., 2005

4.1.6 Recent Expansions and Ongoing Work

Information obtained from AUWSSC, ICRC, and UN-HABITAT through USACE AED-S for this Master Plan indicates that between 2006 and 2009 new piping was installed in the Mir Wais Mina, Mir Bazaar, and Old City neighborhoods located in Districts 6 and 7 of southwestern Kandahar City. These projects have resulted in the installation of 46.6 km of high density polyethylene (HDPE) pipe and replacement of 6.2 km of asbestos pipe with HDPE pipe. Sizes of pipes installed range from 25 mm to 200 mm. Water connection was supplied to 25 mosques, two high schools, and over 2,320 households benefitting over 47,000 residents. A variety of generators, pumps, electrical equipment, and a 400 cubic meter storage tank were also constructed. This work is being pursued by the ICRC.

CIDA and UN-HABITAT are currently working on strategies to supply District 9 with water. This is an area of the city mostly without access to piped water that has experienced a large influx of IDPs and refugees. Kandahar University is also located just north of the Loy Walla Canal in this area. The focus of this effort aligns well with the goals and objectives of the Master Plan.

ISAF is also currently pursuing work in District 9 in conjunction with development of the Master Plan. ISAF is assessing strategies to help meet the immediate need for water in this area of the city by constructing watering points and filling via tanker trucks owned by AUWSSC. By focusing efforts on District 9, ISAF and UN-HABITAT are working towards improving the situation in one of the most critical areas in need of water supply. Coordination of resources and combining planning efforts will enable resource allocation efficiency and maximize benefits to the city.

4.1.7 Electrical Supply

Diesel generators appear to be the most common way to power water supply equipment. Solar powered pumps are currently being considered to produce power to operate water pumps. The efficiency and reliability of the water supply system depends on maintaining a pressurized distribution system to avoid infiltration from the ground. This can only be achieved if elevated storage tanks are incorporated into the system or if the pumps run continuously. The information available indicates that the distribution system is partially pressurized when the pumps are working. However, the intermittent electrical service, suggests that the system is susceptible to infiltration of contaminated groundwater most of the time.

4.1.8 Operation and Maintenance

The water supply and distribution management structure in Kandahar City is lacking. Because the majority of the wells are privately owned and dug for personal use by a combination of individual households, international organizations, and NGOs, it is difficult to track or regulate groundwater development activities. The public water system in Kandahar City and the rest of Afghanistan is currently operated by AUWSSC but used to be operated by CAWSS. There are very few historical records available.

Nine of the municipal wells in Kandahar City are reported as operational. No treatment is provided at any locations. Chlorination at AUWSSC headquarters (wells 1, 2 and 3, 11) is possible but has not occurred within the last two years. Due to leaks throughout the system, intermittent electrical service and subsequent lack of constant pumping pressure, the system is susceptible to infiltration of contaminated groundwater most of the time. AUWSSC currently has neither resources nor staff to address problems with the existing system.

4.2 Existing and Future Water Demand

4.2.1 Domestic Water Standards

The amount of water used by a household is determined primarily by distance to the source and/or time for collection. The WHO shows that these differences are primarily observed at four broad service levels of no access, basic access, intermediate access, and optimal access as indicated in Table 13. Health is the most significant indicator of service levels. As access levels increase, the concerns with health decrease.

After discussion with the project team, it was determined that a design criteria of the Master Plan would be to provide 100 liters per capita per day (lpcd) level of service which corresponds to the optimal service level. After further discussion with AUWSSC, it was indicated that the locally preferred service level design criteria is 120 lpcd, also corresponding to the optimal service level. In reality, most of the population of Kandahar City suffers from no access and any improvement on the existing situation would be considered a positive step. Considering that the currently supplied water from the municipal wells is not treated, the water quality is inadequate and concerning from a health standpoint.

Table 13. World Health Organization Service Level Descriptions

Service level description	Distance/time measure	Likely quantities collected	Level of health concern
No access	More than 1000m or 30 minutes total collection time.	Very low (often less than 5 l/c/d).	Very high as hygiene not assured and consumption needs may be at risk. Quality difficult to assure; emphasis on effective use and water handling hygiene.
Basic access	Between 100 and 1000m (5 to 30 minutes total collection time).	Low. Average is unlikely to exceed 20 l/c/d; laundry and/or bathing may occur at water source with additional volumes of water.	Medium. Not all requirements may be met. Quality difficult to assure.
Intermediate access	On-plot, (e.g. single tap in house or yard).	Medium, likely to be around 50 l/c/d, higher volumes unlikely as energy/time requirements still significant.	Low. Most basic hygiene and consumption needs met. Bathing and laundry possible on-site, which may increase frequency of laundering. Issues of effective use still important. Quality more readily assured.
Optimal access	Water is piped into the home through multiple taps.	Varies significantly but likely above 100 l/c/d and may be up to 300l/c/d.	Very low. All uses can be met, quality readily assured..

Source: World Health Organization, 2003

4.2.2 Kandahar City Demand

Using population estimates and projections developed for this project, water supply planning demand for Kandahar City was developed using 120 lpcd as depicted in Table 14. For planning purposes, this figure is used to assess the potential of water supplies to sustain long-term needs and in designing water distribution infrastructure.

Table 14. Water Demand Projection

Growth rate	3.00%	Water Demand		
Year	**Population**	**m^3/hr**	**m^3/day**	**m^3/month**
2010	655,636	3,576	78,676	2,360,290
2011	675,305	3,683	81,037	2,431,099
2012	695,564	3,794	83,468	2,504,032
2013	716,431	3,908	85,972	2,579,153
2014	737,924	4,025	88,551	2,656,528
2015	760,062	4,146	91,207	2,736,223
2016	782,864	4,270	93,944	2,818,310
2017	806,350	4,398	96,762	2,902,859
2018	830,540	4,530	99,665	2,989,945
2019	855,457	4,666	102,655	3,079,644
2020	881,120	4,806	105,734	3,172,033
2021	907,554	4,950	108,906	3,267,194
2022	934,780	5,099	112,174	3,365,210
2023	962,824	5,252	115,539	3,466,166
2024	991,709	5,409	119,005	3,570,151
2025	1,021,460	5,572	122,575	3,677,255
2026	1,052,104	5,739	126,252	3,787,573
2027	1,083,667	5,911	130,040	3,901,200
2028	1,116,177	6,088	133,941	4,018,236
2029	1,149,662	6,271	137,959	4,138,783
2030	1,184,152	6,459	142,098	4,262,947

Based on the estimated current production and maximum production capacity of the existing wells in Kandahar City the graph in Figure 10 depicts the water deficit. This graph assumes maximum production of existing wells is realized, meaning the water deficit is equal to the demand less maximum production. Since water in the shallow aquifer system is considered to be brackish the water supply also does not meet the basic needs of the population in terms of quality.

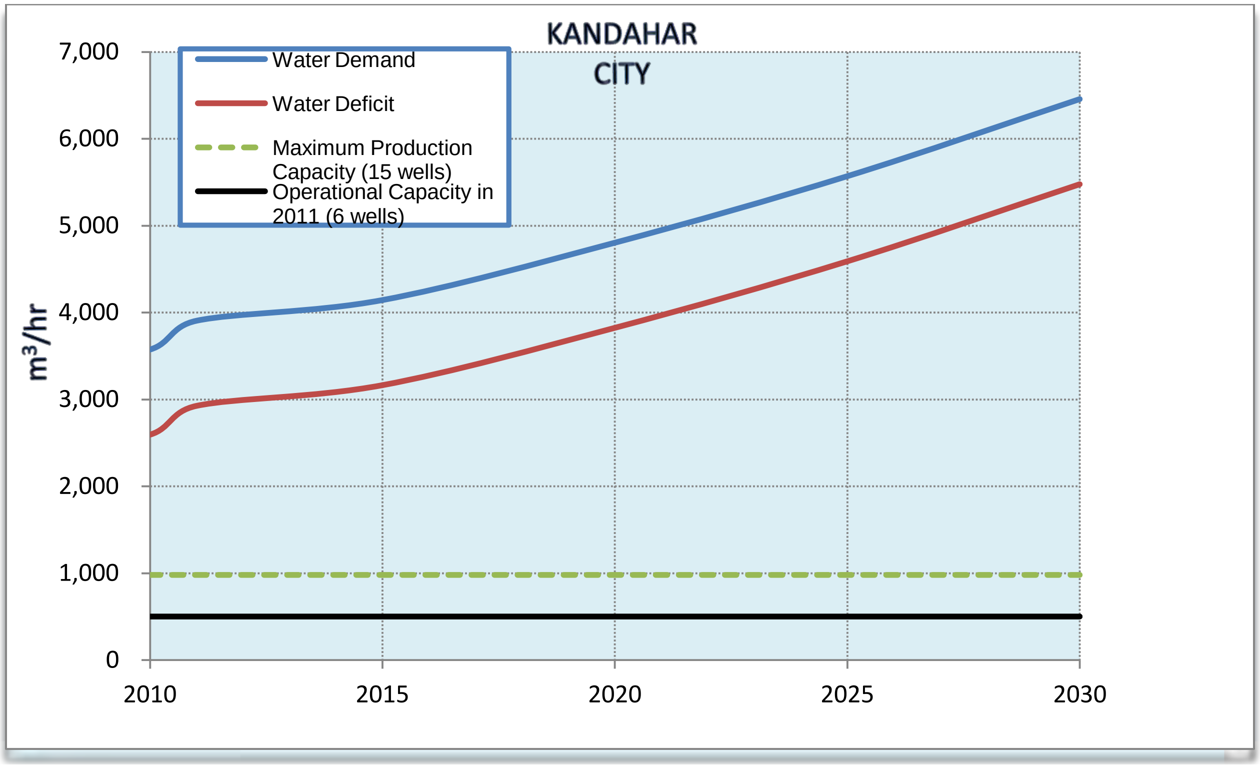


Figure 10. Water Demand and Deficit Compared to Maximum and Current Production

4.2.3 Industrial Use

Data pointing to existing industrial and commercial usage were presented in Sections (give number and name of sections) of this Master Plan. Creating quantitative and actionable metrics was not achieved. As previously stated, to draw any unambiguous conclusions as to the impact of water infrastructure on the economic capacity of the Kandahar Province or City would be difficult. A survey specifically tuned to the particulars of water, its use and its potential use, would be necessary, as opposed to the more demographic or structural-based information presented. Industrial activity occurring in Kandahar City were discussed previously, however the size of these industries is not well articulated so inferences on employment, water use, and future potential are not possible.

4.2.4 Peak and Summer Demands

Peak demand on a seasonal basis occurs during July and August when irrigation need is highest. The situation in Kandahar City does not lend itself to water uses beyond the basic levels needed to sustain health. Summer demand is not influenced by public works projects or municipal services such as fire departments or recreation. The peak planning demand is based on the estimated total current population of 675,000 people and the anticipated growth by 2030 to 1.2 million people with a per person daily demand of 120 lpcd.

4.3 Wastewater and Solid Waste Management

Water-borne disease in developing countries leads to millions of deaths and illnesses annually. Water disinfection is one of several interventions that can improve public health, especially if part of a broad program that considers all disease transmission routes and sustainably involves the community.

Wastewater and solid waste management is currently a serious problem in Kandahar City. The following information is generally derived from JICA (2003). In 2003, it was reported that 99% of houses are without a septic tank to outlet human waste. Waste is disposed of using a traditional method that involves removal at night through a small opening in the lot boundary wall. No data exist for collection of waste, but it typically occurs at night by a special group of unpaid people who use metal ladles to scoop waste through the opening into a container. Waste used to largely be disposed of on agricultural fields for benefit as fertilizer but due to fewer farmers in the desert due to drought, more people are carrying it directly to garbage bins. Those who do have septic tanks reportedly pump them directly into the gutter when they become full.

Solid waste is defined as brick scraps and mud from construction sites, agricultural waste, kitchen waste, plastics, and night soil from houses. Solid waste is either thrown into a gutter or garbage bin, often not fully being removed and lingering. Data are not readily available; the lack of formal waste management is affecting the health of the population.

Solutions to the wastewater problems are currently being explored under a separate study.

5.0 PROBLEMS, OPPORTUNITIES, OBJECTIVES, AND CONSTRAINTS

5.1 Water Supply Problems

The overall problem is that there currently is not a dependable source of safe drinking water being supplied to residents of Kandahar City.

- In Kandahar City, the majority of the population has very little or no access to basic water supply services necessary to meet daily needs and protect health.
- The existing water distribution system is not reliable and the local management agency responsible is understaffed, underfunded, and lacks the training required to operate and maintain the system.
- Kandahar City lacks a reliable source of electricity to provide power for water pumps.
- Kandahar City lacks a wastewater and solid waste treatment system which results in wastewater infiltrating the shallow aquifer.
- Kandahar City lacks records that allow for developing water use trends, fully understanding peak demand, and the ability to charge users for water.
- Municipal and household wells in the city are withdrawing water from the contaminated shallow aquifers, which directly and adversely affects the health of the population.
- Water supply development efforts in the region presently lack coordination at the local, provincial, and national levels of government.
- Lack of equitable and shared access to water between agricultural users, formal residents, and informal residents including IDPs and Kuchis, enhances tension and social instability in the community.
- IDP migration into the city is expected to continue to occur in Kandahar City, and specifically District 9, and their presence is not officially recognized and highly controversial.
- Drought, population increases, and environmental and economic needs have heightened competition for scarce water resources.

5.2 Opportunities

Opportunities that exist to improve the overall water supply situation in Kandahar City include:

- Provide water to underserved residents, specifically those with no access to piped water.
- Provide safe drinking water to the entire population in the city.
- Improve access to water and quality of life in the low-income peripheral areas of the city.
- Reduce conflicts over waters caused by recent influxes of refugees and IDPs.
- Increase understanding of availability and sustainability of regional deep aquifers.
- Improve the existing distribution system network, including pumps, generators, and storage tanks.
- Expand the existing distribution network to provide services to underserved area.
- Promote a participatory and inclusive process to increase water access across social classes.
- Improve water conservation practices at the household level and throughout the community.

5.3 Project Goal

The goal of the Kandahar City Water Supply Master Plan Project is to provide access to safe drinking water to the residents of Kandahar City as quickly as possible and in the long-term.

This goal is consistent with the U.S. Government Inter-Agency Water Strategy (USWS) for Afghanistan and the Afghanistan National Development Strategy (ANDS). The USWS for Afghanistan was approved in March, 2010 as the guiding strategic approach behind U.S. water sector development efforts in Afghanistan through fiscal year 2014. The Afghan Government issued the Afghanistan National Development Strategy (ANDS) Water Resource Management Sector Strategy in 2008 which is intended to guide development through 2013. Both strategies seek to provide improved social and economic benefits that will improve the quality of life and help reduce poverty while aiming to improve the management of Afghanistan‘s water resources. Water supply and sanitation is a key area of each government‘s strategy. Specifically, both the U.S. and Afghan water development strategies have a goal explicitly directed at improving overall access to safe water for drinking.

5.4 Project Objectives

The objectives for this project were developed by the PDT with the intent of meeting the goal to provide access to safe drinking water to residents of Kandahar City in a timely manner. Objectives were initially developed at the kick-off meeting for this project and refined throughout as the planning process progressed. Initially, the project was primarily focused on assessing groundwater development. When it became apparent the regional aquifers would be unable to meet long-term demand of the population, the project began evaluating surface water from the Arghandab River, specifically from Dahla Dam. Objectives were also developed with input that was received from AUWSSC, Ministry of Energy and Water (MEW), and other local organizations. The objectives of this project are:

1. Meet near-term basic access needs of 20 lpcd and long-term optimum access needs of 120 lpcd for the population of Kandahar City. (Objective 1 will be accomplished by assessing regional surface water resource conditions and conditions in regional deep and shallow aquifers.)
2. Near-term water supply sources should focus on meeting minimum water quality requirements using less resource intensive treatment methods such as disinfection, in order to enable quicker and more practical water access to the population. (Objective 2 will be accomplished by assessing water quality of surface water and the deep and shallow aquifers.)
3. Determine the suitability and feasibility of a Ranney well system relative to traditional vertical wells.
4. Identify components needed to connect the initial three deep groundwater wells to the existing distribution system.
5. Identify the overall recommended treatment, storage, and transmission components required to supply Kandahar City with a reliable water supply system.
6. Identify an overall conceptual design and approach for distribution phasing, cost estimates, and guidelines for operation and maintenance by Afghans.
7. Produce documents suitable for donors based on the objectives above.

For planning purposes, water supplies required to meet near-term demand are a minimum of 20 lpcd and to meet long-term demand the requirement is 120 lpcd. Since the desirable long-term demand is 120 lpcd this figure is used as a design guideline to determine pipe sizes using a model of the distribution system. The demand of 20 lpcd is from World Health Organization (WHO) criteria that are utilized for areas that have a water distribution point and where residents need to carry water from the water distribution point to their homes (Howard &Bartram, 2003). The maximum water demand of 120 lpcd is criteria provided from AUWSSC for water provided directly to the home. The peak demand is based on the estimated total current population of 675,000 people and the anticipated growth by 2030 to 1.2 million people with a maximum per person daily demand of 120 lpcd. The purpose of modeling the system at both demands is to ensure that the system will be pressurized under various supply scenarios, while specifying pipe sizes that meet the high-end demand.

5.5 Project Constraints

These following study-specific constraints affect the development and evaluation of alternatives in the master planning process:

1. Collection of necessary survey and field data is hindered by the location of the project in a conflict zone.
2. Security issues need to be considered for proposed alternatives.
3. Operation and maintenance requirements may limit consideration of certain alternatives.
4. Kandahar City lacks reliable municipal infrastructure that is necessary to support a fully functioning water supply system.
5. Kandahar City lacks well-established supporting mechanisms in government and industry to finance, maintain, and manage a water supply system.
6. Existing water supply from the shallow aquifers currently is not suitable for human consumption (unless treated).
7. Information related to the condition of the existing water supply infrastructure, well locations, water quality, social effects, and other environmental data is limited due to lack of record keeping and inability to perform site visits.
8. Development of alternatives is limited by the location of the project and lack of experienced contractors.
9. Lack of setback distance and government-owned land along roadways makes real estate acquisition potentially challenging.
10. Very limited pool of experienced design and construction firms with experience building water supply infrastructure in this region.

6.0 EVALUATION OF MASTER PLANNING OPTIONS

6.1 Groundwater Supply Options

Potential alternative groundwater sources were identified primarily based on relationships among geology, hydrogeology, recharge, and discharge zones. In addition, contractibility issues such as grade, pumping requirements, and distance to the planned distribution system were evaluated. Using the best data and science available to the project team, several predictive scenarios were modeled at locations exhibiting the most potential as a source of municipal water supply. The goal of this effort was to identify areas where groundwater resources could be utilized to meet the water supply needs of Kandahar City in a sustainable manner. Objectives of the Master Plan addressed during this assessment include:

- Meet near-term basic access needs of 20 lpcd and long-term optimum access needs of 120 lpcd for the population of Kandahar City. (Objective 1 will be accomplished by assessing regional surface water resource conditions and conditions in regional deep and shallow aquifers.)

- Near-term water supply sources should focus on meeting minimum water quality requirements using less resource intensive treatment methods such as disinfection, in order to enable quicker and more practical water access to the population. (Objective 2 will be accomplished by assessing water quality of surface water and the deep and shallow aquifers.)
- Evaluate the Ranney well to determine the suitability and feasibility of this type of system.

The model simulations help assess regional sources of groundwater and the response of the regional aquifer systems to potential future groundwater withdrawals. The results of these simulations provide a good indication of the best alternatives for groundwater to provide potable water to Kandahar City. Four options were identified and considered. Each groundwater option considered was evaluated to determine if it meets the planning objectives.

Figure 11 shows the four locations where model simulations were performed. Zone 1 is in the Deep Aquifer along the Tarnac River. This zone was selected based on the promising results of the Camp Lassano and Seabee test wells that have recently been installed in the vicinity of KAF. Zone 2 is located north of Kandahar City between the western bank of the Arghandab River and the mountains west of Ant Valley. This location was selected to simulate either a shallow groundwater extraction system or Ranney well in the Arghandab Valley. Zone 3 is located in Ant Valley north of Kandahar City. This location was selected to evaluate the on-going effort to install new groundwater wells in this area. Zone 4 includes the existing water supply wells in Kandahar City. The intent of this simulation is to evaluate the impact of increased withdrawal from the existing well system.

At each location, simulations were made to assess groundwater withdraw at several different extraction rates. Below is a summary of the extraction rates and their relationship to water demand of the Kandahar City population. For a summary of population estimates, projections, and demand refer to Sections 2.1 and 4.2.

- 1,000 m^3 / day withdrawal rate was modeled to simulate a very low withdrawal rate to evaluate potential areas with low, yet sustainable potential groundwater yields.

- 10,000 m^3 / day withdrawal rate was modeled because it is equivalent to the demand required to meet the needs of a population of 500,000 people at a rate of 20 liters per person per day.

- 60,000 m^3 / day withdrawal rate was modeled because it is equivalent to the demand required to meet the needs of a population of 500,000 people at a rate of 120 liters per person per day.

- 144,000 m^3 / day withdrawal rate was modeled because it is equivalent to the demand required to meet the needs of a population of 1.2 million people at a rate of 120 liters per person per day. For modeling purposes the long-term demand was rounded up from a projected population of approximately 1.8 million requiring 142,000 m^3 / day.

The simulated drawdown for each proposed pumping simulation was plotted on a log-log plot. The proposed pumping rate was on the X-axis (horizontal axis) and the simulated drawdown at a selected location was on the Y-axis (vertical axis). These plots produced reasonably linear curves at each location where drawdown was evaluated. The acceptable production rate for each production zone was identified as the minimum rate that correlated with the performance criteria drawdown (refer to Appendix B for details). For planning purposes, the anticipated well yield would be approximately 13,700 and 9,000 m^3 / day for production Zones 1 and 2, respectively. Model results and recent field investigations do not indicate that a substantial groundwater resource exists in the Ant Valley area (Zone 3). Concerns related to water quality degradation and consequent long term sustainability may limit substantial increases (above the approximate 10,000 m^3 / day) in the water supply capacity of the existing well system in Kandahar City (Zone 4).

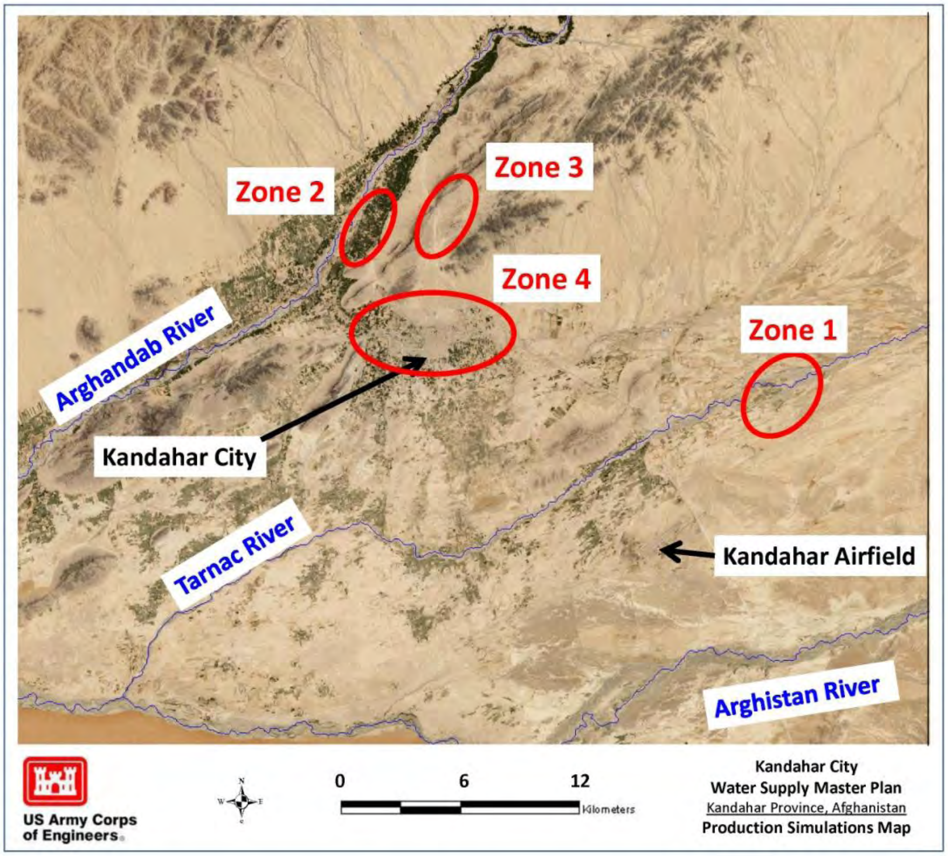


Figure 11. Groundwater Production Simulation Locations

Once the production flow rate was determined for each zone, the simulated stream flow reduction was evaluated. A matrix of computed stream flow reduction and corresponding pumping rate was developed for the three river valleys in the Kandahar Province (Arghandab, Tarnac, and Arghistan). The computed stream flow reduction corresponding to acceptable pumping rate derived from the drawdown analysis was evaluated and determined to be less than the acceptable five percent reduction. The following sections provide a more detailed analysis and results (refer to Appendix B for additional details).

6.1.1 Well Field East of Kandahar City (Zone 1)

Zone 1 is located near the Tarnac River north of the airport and east of Kandahar City. The proposed well field in this location would be drilled to the deep aquifer, which is approximately 260 to 335 meters below ground surface. Indications are that artesian conditions within the deep aquifer and apparent good water quality exist at this location. This artesian condition appears to be the result of groundwater movement through the deep aquifer and bedrock in the vicinity of the Mokur fault, which is believed to underlay the Tarnac River in this area. The presence of this fault apparently extends the recharge area for this aquifer to locations further to the north. Recent data in the city of Qalat, which is approximately 112 km north of proposed Zone 1 in the same Tarnac River basin, also indicate the presence of artesian conditions.

The following three discrete locations were identified to compare computed drawdown as a result of the modeled pumping rates. Table 15 shows the estimated drawdown or reductions of regional water supplies resulting from modeled pumping rates.

Table 15. Zone 1 Production Simulation Impacts

	Drawdown (m)		Change in River Flow (by % of Total Flow)		
Pumping Rate (m^3 / day)	Zone 1 Aquifer	City Aquifer	Arghandab	Tarnac	Arghistan
1,000	2.5	0	0.01%	-0.35%	-0.20%
10,000	24.9	0.2	-0.09%	-3.56%	-1.86%
60,000	152.1	2.4	-1.14%	-23.19%	-8.95%
144,000	373.2*	15.5	-4.82%	-58.76%	-21.47%

*Drawdown exceeds available head

Based on the drawdown levels of the aquifer high-end pumping rates would adversely affect the aquifers and stream flows at this location. After assessing the results of mid- and low-level pumping rates, it became apparent that based on the modeled simulations, the rate limiting factor would be the combination of potential drawdown of the city aquifer in Kandahar City and reduction in base flow to the Tarnac River. If the current well field operations in the city and region are to continue for the foreseeable future, drawdown in Kandahar City area should be minimized. Based on prior studies and discussions with the project team, a maximum drawdown of one meter in the city aquifer in Kandahar City is considered environmentally acceptable.

If one-meter drawdown in the city aquifer in Kandahar City is acceptable from a political and social perspective as well, then a production flow rate of 28,700 m^3 / day from Zone 1 could be used. However, at this pumping rate the reduction in flow to the Tarnac River in the vicinity of Kandahar would exceed the 5% performance criteria for reduction in flow to the river. Pumping may capture water that would otherwise be lost to evapotranspiration, so the simulated reduction in river flow may be less than that predicted by the model. For this reason, a simulated reduction in river discharge of 5% was considered acceptable. A pumping rate of 13,700 m^3 / day from Zone 1 would be achievable without exceeding this flow reduction criterion. This rate would be adequate to supply water to Kandahar City at a level of 20 lpcd for a population of approximately 680,000. This 13,700 m^3 / day extraction rate would result in approximately 3.75 meters of drawdown immediately in the city aquifer in the vicinity of Zone 1. It is believed that a five-meter drawdown of the city aquifer in Zone 1 would most likely have adverse impacts on existing household in the area. Since the proposed pumping would result in a drawdown less than this performance goal, the 13,700 m^3 / day pumping rate for Zone 1 is considered reasonable.

Zone 1

Pros

- This option meets near-term basic access needs for the majority of the existing population by supplying 20 lpcd.
- Pumping at a rate of 13,700 m^3 / day is considered environmentally sustainable.
- Water quality from the deep aquifer is potentially good.
- Due to apparent recharge along a deep subsurface fracture with connections extending far to the north, seasonal variations and drought are less likely to impact the aquifer.
- Due to the flat terrain between the city and the proposed well field a transmission pipeline is technically feasible.
- If pumped at recommended flow rate of 13,700 m^3 / day this source appears sustainable.

Cons

- This option does not meet long-term optimum access needs for the projected population by supplying 120 lpcd, and the aquifer would likely become taxed without supplemental sources.
- At a distance of 10 km east of Kandahar City, the costs of installing a transmission pipeline are likely high.
- Modeling data, water quality, and aquifer limits need to be verified with a test well.

This option does provide a near-term option for water supply which is an important and significant finding. Due to its inability to satisfy the long-term needs of Kandahar City, however, this stand-alone option does not meet project objectives.

Based on discussion with the project team, each well in the new well field may be able to produce approximately 1,090 m^3 / day. If each well were planned to be operated 50 percent of the time (given down-time, well cycling, power limitations, etc.), approximately 26 wells would be needed for this well field.

(For reference, Figure 4.2 in Appendix B summarizes the drawdown computed in the modeling simulations performed for Zone 1. The contours depicted in this figure show the computed drawdown in the deep/rock aquifers for the simulation representing a withdrawal rate of 10,000 m^3 / day.)

6.1.2 Well Field in Arghandab River Valley (Zone 2)

Zone 2 is located in the Arghandab River basin north of Kandahar City. The proposed well field in this location would be drilled to the upper aquifers, above the rock which is estimated to exist 35 to 40 meters below ground surface. Groundwater flow in this area is towards the Arghandab River from the mountains immediately to the east and west, as well as flow southwest down the river. As indicated in Appendix B, the values in this section are considered to be conservative, meaning impacts are likely not overstated.

Drawdown rates in Zone 2 and the city aquifers were modeled and are shown to compare drawdown as a result of the modeled pumping rates. Table 16 shows the estimated drawdown or reductions of regional water supplies resulting from modeled pumping rates.

Table 16. Zone 2 Production Simulation Impacts

	Drawdown (m)		Change in River Flow (by % of Total Flow)		
Pumping Rate (m^3 / day)	Zone 2 Aquifer	City Aquifer	Arghandab	Tarnac	Arghistan
1,000	0.5	0.1	-0.73%	0.00%	0.00%
10,000	16.8	3.0	-4.32%	-0.31%	-0.11%
60,000	124.8*	36.5	-18.83%	-5.83%	-1.94%
144,000	317.2*	101.2	-36.86%	-18.29%	-4.53%

*Drawdown exceeds available head

Based on the drawdown levels of the aquifer high-end pumping rates would adversely affect the aquifers. After assessing the results of low-level pumping rates, it became apparent that based on the modeled simulations, the rate limiting factor would be the potential drawdown in the vicinity of the Zone 2 well field. Based on the land use in the area, the performance criteria for safe yield was determined to be a drawdown that was not below the invert of the Arghandab River in this area. Fifteen meters of drawdown is the threshold at which withdrawals would impact groundwater inflows into the Arghandab River, potentially reversing subsurface flows contributing to gains in the river to losses. Given this criteria, a production flow rate of 9,000 m^3 / day is possible and likely would not impact flows in the Arghandab River. This flow rate would supply around 450,000 people at a rate of 20 lpcd.

If a reduction in discharge to the rivers of 5% is considered acceptable, a production flow rate of just over 10,000 m^3 / day is possible. As discussed in the previous section, a drawdown of one meter in the city aquifer in Kandahar City is considered acceptable. Given this criterion a production flow rate of 3,900 m^3 / day is possible, which would supply around 195,000 people at a rate of 20 lpcd. This flow rate assumes that no recharge to the groundwater system is provided by water flowing down the Arghandab River (i.e. drought conditions). Since under normal conditions the Arghandab River is flowing and used to irrigate a wide riparian area west of Kandahar City, this lower flow rate may be possible under extreme conditions but was not used for planning and design purposes.

For planning purposes, the pumping rate with minimal impacts under normal conditions will be used because it is assumed that near- and long-term sustainability of the aquifer is imperative (9,000 m^3 / day).

Zone 2

Pros

- In a region with scarce water resources, this option presents a source of water which could serve to meet basic access needs for a large portion of Kandahar City, or localized populations in the Arghandab River Valley.
- Pumping at a rate of 9,000 m^3 / day is considered environmentally sustainable.
- Constructing transmission pipeline infrastructure to the city appears technically feasible.
- This well field is situated in close proximity to the area where piped water from Dahla Dam could enter the city, which creates a possibility to optimize the use of treatment facilities.
- Groundwater quality in the alluvium of the river is expected to be good.

Cons

- This option does not meet near-term basic access needs for the existing population by supplying 20 lpcd.
- This option does not meet long-term optimum access needs for the projected population by supplying 120 lpcd, and the aquifer would likely become taxed without supplemental sources.
- This location is thought to have a moderate risk because the well field is vertically shallower and influenced by a smaller drainage area making it more susceptible to drought and other localized water related problems. Infiltration from the Loy Walla Canal is thought to be a contributor to recharge.
- Drawdown of the aquifer could impact irrigation operations nearby. This needs further investigation.
- Modeling data, water quality, and aquifer limits need to be verified with a test well.

This option does provide a near-term option for water supply which is an important and significant finding. However, due to inability to satisfy either the near-term or long-term needs of Kandahar City this stand-alone option does not meet project objectives.

Traditional vertical shallow wells are the suggested well configuration under this option. If each well in the new well field were able to produce approximately 1,090 m^3 / day and operated 50 percent of the time (given down-time, well cycling, power limitations, etc.), approximately 16 traditional wells would be needed for this well field.

6.1.3 Ranney Well Field (Zone 2)

Zone 2 is located in the Arghandab River basin north of Kandahar City. The proposed well field in this location discussed here would be a Ranney configuration. Ranney wells are most commonly applied in riverbank and reservoir infiltration settings where a relatively large and consistent source of recharge is available. During the past decade, this readily available large source of recharge has not been present in the Arghandab River basin due to significant drought conditions. This lack of consistent surface water recharge limits the yield potential from any well or well field. Significant withdrawals of groundwater made from the river valley unconfined aquifer will likely have significant negative affects to local canals, irrigation and existing shallow wells. Without a significant recharge source available, the economic viability of this well type is unsupported due to the resulting limited yields which make less expensive conventional vertical wells more appropriate.

Successful design and construction of a Ranney well requires an experienced contractor team. Based on market research, there are only a very small number of qualified and experienced firms that design and build Ranney wells. Within the United States, all firms that were located are subsidiaries of Layne Christensen Drilling and often contact with these firms lead to the same very small number of professionals. Outside of the United States, only one firm each in Germany, India and Korea were found to have any meaningful experience. This represents a very limited pool of contractors available to complete a Ranney well and limits competitive bidding options.

Actual construction of a Ranney well requires on-site construction of a reinforced concrete caisson excavated to typical depths of 30 to 60 meters. The depth to the top of bedrock at the proposed Zone 2 well location is estimated to be 50 meters, which is within this typical depth/constructability range. After the base is set, the caisson is pumped dry to allow for construction of the horizontal radial well screens. Construction of the horizontal wells requires use of very specialized drilling, pumping and hydraulic jacking equipment that is not common and often custom-built for the application. The benefits of a Ranney well are that if properly designed and built in a well-suited location, one Ranney well can produce yields equivalent to multiple vertical wells, reducing the extent of the distribution network required and limiting the surficial footprint of the supply well network. The cost of one Ranney well is typically ten times the cost of one conventional vertical well set in similar conditions, although cases have been found where this number can approach twenty times vertical well costs depending on the available pool of well drillers and site conditions.

Based on the following rationale, at this time, it is felt that a Ranney radial collector well is not an appropriate method for a shallow unconfined aquifer supply well in the Kandahar, Afghanistan region.

Zone 2

Cons

- Very limited pool of experienced design and construction firms versed in this unique supply well type as compared to more readily available pool of qualified contractors with successful track record for vertical wells in this region.
- The lack of a consistent surface water source for recharge severely limits the anticipated yield potential for an individual Ranney well.
- Under nearly ideal logistical settings, construction duration and costs are significantly higher for a Ranney well as compared to multiple vertical wells. The physical and political conditions in the Kandahar Province will have significant negative impact on both costs and durations that will make the cost-benefit even less appealing especially considering the limited yield potential anticipated based on the groundwater model simulations.
- Both for operation and maintenance (O&M) considerations and security issues, it is believed that a distributed field or network of lower yielding vertical wells may be more appropriate than one individual Ranney type well which lacks redundancy and represents significant critical infrastructure at a single location.

The groundwater modeling project team is peripherally aware of studies involving the rehabilitation of the Dahla Dam and has included multiple simulations for varied reservoir elevations as a component to the model runs. The inability to place a Ranney well directly adjacent to a large consistent recharge source is one of the key limiting factors to its recommended use in the Arghandab River downstream of the Dahla Dam.

There may be value to considering the application of a Ranney well, or a variation on the same idea as a surface water intake using very-long laterals at or below the reservoir bottom tied into a caisson as previously described, in close proximity to the Dahla Dam reservoir. This can have the positive effect of the natural filtering processes inherent in that design as a pre-treatment step. Groundwater extracted from any well as compared to surface waters have reduced TDS and bacteria concentrations as well as reduced temperature and dissolved oxygen ranges which affect the treatment process used and costs. Due to the long screen length and lower entrance velocities, Ranney wells can have more improved water quality than vertical wells in some settings, especially if the vertical wells are poorly constructed and operated. Placement of the Ranney well at this higher elevation may also allow the design to take advantage of gravity to reduce pumping requirements.

6.1.4 Well Field in Ant Valley North of Kandahar City (Zone 3)

Zone 3 is located in the Ant Valley north of Kandahar City. The proposed well field in this location would be drilled to the rock aquifer, which is overlain by approximately 15 meters of unconfined aquifer sands. Groundwater flow in this area is predominantly from the mountains surrounding this valley. The valley floor in the vicinity of Zone 3 is approximately 1,120 meters. The mountain peaks surrounding this area to the north, east and west rise to elevations in excess of 1,700 meters. The mountain peaks in this region are steep and although recharge is applied to the model in this area, recharge through the rock is a limiting factor.

Drawdown rates in Zone 3 and the city aquifers were modeled and are shown to compare drawdown as a result of the modeled pumping rates. Table 17 shows the estimated drawdown and flow reductions at regional water supply locations.

Table 17. Zone 3 Production Simulation Impacts

	Drawdown (m)		Change in River Flow (by % of Total Flow)		
Pumping Rate (m^3 / day)	Zone 3 Aquifer	City Aquifer	Arghandab	Tarnac	Arghistan
1,000	10.7	0.1	-0.46%	0.02%	0.01%
10,000	107.8*	1.8	-4.14%	-0.29%	-0.11%
60,000	663.4*	26.7	-18.43%	-5.69%	-2.03%
144,000	1611*	79.2	-32.68%	-19.16%	-5.71%

*Drawdown exceeds available head

Only the lowest pumping rate production simulation for Zone 3 computed drawdown that was not below the top of the Rock Aquifer. All model simulation with pumping withdrawal rates above one tenth of the low production rate of 20 liters per person per day for 500,000 people resulted in computed drawdown that would not be physically possible (drawdown below the bottom of the well). Therefore, it is possible that production rates in this area may be on the order of 1,000 m^3 / day.

This low potential production rate is in part due to the relatively shallow depth to magnetic rock based on available USGS data in this area and relatively low hydraulic conductivity of the rock. According to the Fracture Trace analysis performed for the Kandahar Province, there is a potential for fractures in this area which could act as conduits to any potential well field (USGS, 2007). These fractures could increase the potential of this area as a viable source of water if the fractures were to connect the nearby recharge area in the mountains to the new well field. However, recent well drilling activities in this area for the COP-9 wells indicate a flow rate of only 65 to 235 m^3 / day. During pump testing of the wells within this new well field, interaction was seen between these wells. Questions have been raised concerning the drilling and completion of these wells, which may be limiting production of the wells which were at the low end of the observed production range. Additional well drilling operations are planned in promising fracture areas within the Ant Valley. Although further investigation in this area may be warranted to identify rock fractures that convey groundwater, the available data do not support significant groundwater availability at this time.

Unless additional information is provided showing different outcomes within the model, due to inability of this option to meet basic needs of a substantial portion of the population in Kandahar City it has been eliminated from consideration at this time. Currently there are ongoing drilling efforts in this area that will help evaluate the presence of groundwater.

6.1.5 Increased Well Development in Kandahar City (Zone 4)

Zone 4 is located in Kandahar City. The intent of this simulation is to evaluate the impacts of increasing the yield from the active water supply wells within the city. Based on limited data published in the 2003 CDM report, it appears that the safe yield rate was approximately 2 to 3 times greater than the pumping rate used for calibration. Although substantial uncertainty exists related to which wells are operational and the actual pumping rates of these wells, simulations performed in this evaluation are useful in identifying the cones of depression in Kandahar City. The wells used in these simulations reflected the wells where adequate location, well construction, and pumping rate data existed. However, substantially more wells where some or all of this data does not exist are believed to exist in Kandahar City.

A comparison of the simulated drawdown for the calibrated model and safe yield production rate simulations shows a significant increase in the magnitude of the cone of depression. The maximum drawdown occurs in the vicinity of the cluster of wells containing Mech Lycee, CAWSS TW 1, CAWSS TW 2, and Ahmad Shah Baba Lycee. The average cone of depression in this area when the production rates from the existing operational well is increased by two to three times is approximately 27 meters. Local cones of depression at the Mah Bas Prison and Sadat Ghundai wells, which are both near the Gap, exceed 20 meters.

The majority of the larger supply wells in Kandahar City draw from the upper confined and/or city aquifers. It is believed that many of these wells also are able to draw water from the unconfined aquifer either through their filter pack, poor well construction, or other means. Under un-pumped conditions the vertical gradient in the confined semi-confined aquifers varies. There is a general downward trend in vertical gradient near the higher elevation mountain areas, where recharge is believed to occur. In the lower lying areas, this downward gradient shifts to an upward gradient as the topography decreases in elevation. The populated portion of Kandahar City lies between these two areas, resulting in a static condition that is relatively flat to marginally downward. Pumping appears to reverse and/or increase this vertically-downward gradient. The computed drawdown from this Zone 4 production simulation results in water levels that are at or within the elevation of the upper confined aquifer and generally slightly above the city aquifer.

Although the average Kandahar City production well withdrawal was estimated by CDM to be 3,158 m^3 / day, the total groundwater withdrawals in Kandahar City may be 10,000 m^3 / day according to the same report. The calibration simulation used a combined withdrawal rate of 7,776 m^3 / day, which is reasonably consistent with this total withdrawal estimate provide by CDM. The Zone 4 production simulation assumes a total withdraw of nearly 20,000 m^3 / day. If a safe yield is considered to be drawdown to the top of the aquifer from which the water is withdrawn, the projected pumping simulation indicates that the current well system in Kandahar City at maximum pumping rate of 10,000 m^3 / day would be near to or at capacity. Additional drawdown in the vicinity of the city would increase the potential for vertical migration of lower quality water in the upper aquifer to the water of higher quality in the confined aquifers. This may result in long term degradation of the aquifers currently being used for water supply and increase treatment requirements of the water.

If groundwater withdrawals in Kandahar City are increased, significant increases in the cone of depression are observed and a potential increase in water quality degradation exists. While some potential for strategic drilling in the deep aquifer of a handful of additional wells may exist, this stand-alone option does not meet long-term need and does not satisfy the project objectives.

6.1.6 Subsurface Dams

A subsurface dam is a scalable technology where a barrier (dam, cut-off wall) is placed across an ephemeral stream or river to increase the elevation of the water table on the upstream side of the dam, increasing the volume of stored water within upstream sediments. This technology has been in use in arid and rural regions of the world for hundreds of years. Since the 1990's, a number of these subsurface dams has been scaled up from small village level structures around a couple meters tall supplying water to a few dozen, to much larger structures through the use of mixed-in-place slurry-walls methodologies (Ishida, Tsuchihara, Yoshimoto, & Imaizumi, 2011). These larger projects are used to provide a large and regular supply of water for irrigation and potable supply in arid islands of Japan and a proposed project in a wadi in Saudi Arabia. A summary of recent subsurface dams listed in Ishidaet al. (2011) includes projects with total reservoir volumes ranging from 12 m^3 up to 10,500 m^3 with dam heights ranging from 3 meters up to 110 meters. Construction methods include grouting, slurry wall, sheet steel, mix-in-place, clay and concrete wall, and lower tech solutions such as plastered brick, plastic sheeting, mixed stone rubble brick and mortar. Projects have been completed in Kenya, Brazil, Ethiopia, China, and Korea to name a few.

Subsurface dams are also known by other terms such as groundwater dams, underground dams and cut-off walls. There are a number of advantages to subsurface dams as compared to surface dams:

- Because the structure is buried and supported on all sides, there is significantly reduced concern with structural failure.
- Subsurface dams store a percentage of water that is typically lost as runoff during high flow events within the pore spaces in the sediment.
- Subsurface water storage while reduced in volume due to the sediment volume has significantly reduced evaporative losses compared to surface storage.
- Subsurface dams can provide enhanced recharge to shallow groundwater aquifers and/or provide a longer term source for what could have been lost runoff.

Key design criteria include the need to tie the base of the dam into a low permeability unit such as low hydraulic conductivity bedrock or clay aquitard (i.e., zone within the earth that restricts the flow of groundwater between aquifers). If the base and sides of the dam are not keyed into lower permeability geologic units, then the structure will not function as designed, although if the leakage is downward it is still enhancing groundwater recharge. Another key design consideration is to avoid producing an elevated water table on the upstream side which if fluctuated frequently could increase soil salinity concerns, especially in this region (Hanson & Nilsson, 1986). The volume of available stored water will be a function of the effective porosity of the sediment on the upstream side of the dam (typical sand and gravel porosities range from 20 to 30 percent of the sediment volume available).

If desired, water extraction wells on the upstream side and/or gravity drains can be designed into the dam structure to allow for water supply extraction. Further investigation of subsurface dams is possible and if recommended following local and agency input would be included in the final Master Plan. Potential sites, environmental impacts, costs, construction methods, and quantification of benefits would be assessed as needed.

6.1.7 Sand Dams

Sand dams are similar in idea to subsurface dams in that they restrict surface water flow in ephemeral or even perennial streams and rivers with significant fluctuation, but they differ slightly in construction and approach. Like a subsurface dam, a sand dam is a scalable technology where a low permeability barrier is constructed into a low permeability unit such as relatively competent bedrock and constructed in steps or stages over time. For example, after stage one is built and keyed into bedrock, it may create a small dam across the channel a few meters tall. During the next significant rain event when high energy levels carry coarser grained sediment, the initial coarse sediment is trapped on the upstream side of the dam and eventually water levels raise until the dam is overtopped, returning flow to the downstream channel. This effectively raises the stream bed on the upstream side and increases the volume of available groundwater storage. During periods of lower energy flow, the finer grained sediment is allowed to transport down river. The second and repeated stages of construction occur during subsequent dry seasons, again raising slightly the dam crest and also sloping upstream for stability. This process can be repeated at one location and multiple structures can be built within a drainage channel for stepped sand storage of what would typically be a flash storm/flood event and quickly lost to runoff and evaporation.

This technology shares many of the same benefits as a subsurface dam and both have established track records as projects completed by many governmental organizations and NGOs worldwide including the World Bank and the United Nations (United Nations Environment Program, 1999). Wells or gravity piping may also be incorporated in to these designs.

Further investigation of sand dams is possible and if recommended following local and agency input would be included in the final Master Plan. Potential sites, environmental impacts, costs, construction methods, and quantification of benefits would be assessed as needed.

6.1.8 Sources of Error and Uncertainty

Due to the large quantity of data collected for this modeling effort and the heterogeneities inherent in the units being modeled, several potential sources of error exist. The data used for model construction and calibration were compiled from numerous sources. Each source of data recorded information (water level, pumping rates, lithologic information, etc) in a different manner. Data collection and transcription errors were identified as best as possible. Although every effort was made to minimize the effects of these errors, it was not possible to eliminate all error from the data used in model calibration.

Limitations in the data coverage (temporal and spatial) and availability in this area were significant. The modeling team attempted to use this sparse data to the maximum extent possible to develop a useful tool to evaluate water supply issues in Kandahar City and the surrounding area. The uncertainty resulting from data limitation and other sources of error will be more fully quantified in the final groundwater model report. As additional data are generated for this area, refinements to the model and its calibration will greatly enhance its reliability and usefulness as a predictive tool.

As discussed in the assessment of groundwater options, a test well at each proposed well field is recommended to verify the modeling outputs and determine the actual limits of the aquifer. The information obtained from these efforts would be invaluable to ensuring wise investments of funds.

6.1.9 Summary of Groundwater Options

The following preliminary recommendations are made:

1. Primary focus for the majority of the likely higher quality potable water supply should be in Zone 1 - deep aquifers east of Kandahar.
2. Based on the apparent substantial source of water in the shallow aquifer in the Arghandab River Valley, consideration should be given to a traditional well field in this location.

3. Only if the findings of the groundwater modeling simulations indicate that a useful percentage of the required supply demand can be obtained without producing negative effects to surface water, groundwater and related irrigation systems, then proceed with vertical well / well field testing, design and construction.
4. Ranney wells appear to be a poor alternative for shallow water supply in the proposed Zone 2 location for a number of reasons outlined above. Depending on the scope of the Dahla Dam rehabilitation project, consider the inclusion of this type or similar surface water intake well into that project.
5. Enhanced recharge projects including subsurface dams and sand dams are worth evaluating further as separate, yet related components to increasing the sustainable long-term supply of potable drinking water to this arid region.
6. Subsurface dams and sand dams are likely useful alternatives for providing small-scale and localized supply of potable shallow groundwater for outlying areas which may reduce water consumption pressures on Kandahar City and should be evaluated.
7. Education, organization and control over wellhead protection, well construction and land use master planning should be another aspect to improving and protecting the valuable water resources within the region.

Although it is beyond the scope of the current study, treatment and reinfiltration of wastewater may prove to be a viable mechanism to recharge the groundwater system in the vicinity of Kandahar City. However, it must also be recognized that increases (more than 10-fold based on current estimates) in water supply to this area will inevitably lead to more wastewater generation. If this additional wastewater is left untreated, as is the current practice, the sustainability of the current groundwater resources may be degraded.

6.2 Surface Water Supply Options

Surface water options to supply Kandahar City were assessed using water resources data and reports from previous water investigations. Because of the scarcity of water resources in the region, this effort was able to quickly identify and assess potential options. Surface water in Kandahar Province is driven primarily by precipitation and snowmelt in the upper portions of the watersheds above Kandahar City. Precipitation peaks in the months of March and April, and along with snowmelt, provides the primary source of flow to the region's rivers. Surface water from the Arghandab, Tarnac, and Arghistan Rivers is in high demand by farmers. Dahla Dam north of Kandahar City supports a large amount of irrigation in the Arghandab watershed below the dam and above the city. The network of irrigation canals supplied by the dam have historically been dependable but during times of drought the reservoir and canals have dried up leaving farmers without this crucial source of water.

Objectives of the Master Plan addressed during this assessment include:

- Meet near-term basic access needs of 20 lpcd and long-term optimum access needs of 120 lpcd for the population of Kandahar City. (Objective 1 will be accomplished by assessing regional surface water resource conditions and conditions in regional deep and shallow aquifers.)
- Near-term water supply sources should focus on meeting minimum water quality requirements using less-resource intensive treatment methods such as disinfection, in order to enable quicker and more practical water access to the population. (Objective 2 will be accomplished by assessing water quality of surface water and the deep and shallow aquifers.)

6.2.1 Loy Walla Canal in Northern Kandahar City

Currently, residents in Kandahar City and others along the Loy Walla Canal (see Figure 9) without access to municipal water are thought to utilize its water for domestic purposes. Mostly, it is a dependable source of irrigation for farmers but has been known to dry up during droughts. Consideration of canals for municipal water requires assessing their existing use both from a water budget and socio-economic perspective. The total dissolved solids in surface water of the Arghandab River and the Loy Walla Canal have been found to be less than 350 mg/L (Sammel, 1971). This compares with total dissolved solids in surface water of the Tarnac River of 1,100-1,540 mg/L (4 samples) and 960 mg/L (1 sample) in the Arghistan River. The Loy Walla Canal is generally unlined and water infiltrates the subsurface as it flows through Kandahar City. Despite low total dissolved solid levels reported, water is untreated and likely not safe for consumption.

The Loy Walla Canal is part of the AIP, which originates at the Arghandab Headworks and follows the Arghandab River south before turning east and passing through northern Kandahar City. From there the canal continues through the flat basin east and south of Kandahar City. Most of the water in the system is intended for irrigation. According to information retrieved from CIDA (2008), irrigators require water from the Arghandab system from April to November with peak demand occurring in July and August. The total irrigation demand is around 800 million m^3 / year. Reports indicate that under the current situation, irrigation demand is not met by the water released into the canals.

Mirabs control water that is diverted from the primary canals into secondary and tertiary canals for irrigation. There is generally a lack of education to raise awareness of water conservation and training to improve agricultural practices and water use efficiency. Information on the existing canal network was derived from prior reports and despite being unable to conduct site visits during the study period the CIDA (2008) report has good information on the existing canal network. Based on that report, the existing canal network is very inefficient due to "high conveyance loss in the delivery system, lack of well-designed gated control structures, and high on-farm water losses caused by over-irrigation, mismanagement of the irrigation water, and poorly leveled land."

Based on the information available, the ability of the Loy Walla Canal to supply substantial volumes of municipal water to Kandahar City under the current situation is not likely. The current volumes of water are failing to meet irrigation demand each year. It is unlikely that even with a more efficient canal system, better conservation and agricultural practices, and more efficient allocation of water, the system would have excess water for irrigation. Diverting a substantial portion of water currently allocated for irrigation would likely have socio-economic impacts throughout the region because of the importance of the resource to the economy. As a short-term option, this is likely undesirable due to the treatment needs associated with using surface water for domestic purposes.

This option is eliminated from further consideration as a municipal source of water.

6.2.2 Arghandab River West of Kandahar City

Using surface water from the Arghandab River for municipal purposes is considered because it is a perennial stream situated at the west end of Kandahar City. This option would include placing an intake directly in the river in a location nearby the city. Water supply in the river would need to be continuous and provide adequate volumes to meet demand throughout the year. Flows are currently controlled in the river by Dahla Dam which stores water for use during the irrigation season and the AIP which diverts water from the river to the system of irrigation canals. Uncontrolled spills do occur but not on a continuous basis. Additionally, peak flows in the river are driven by spring precipitation and snowmelt.

The total dissolved solids in surface water of the Arghandab River and the Loy Walla Canal have been found to be less than 350 mg/L (Sammel, 1971). This compares with total dissolved solids in surface water of the Tarnac River of 1,100-1,540 mg/L (4 samples) and 960 mg/L (1 sample) in the Arghistan River. The Loy Walla Canal is generally unlined and water infiltrates the subsurface as it flows through Kandahar City. Despite reportedly low total dissolved solid levels water is likely unsafe for immediate consumption.

This option is eliminated from further consideration because base flows in the river are currently being reduced by the dam and irrigation diversions. A more likely option for municipal water in this location would be to draw it from the aquifer beneath the river using a traditional well field configuration, which was discussed earlier.

6.2.3 Dahla Dam Reservoir

Using the existing storage or increasing storage capacity at Dahla Dam to provide for municipal use is being considered due to its potential as a long-term sustainable supply. In addition to the significant hydrologic and hydraulic analysis needed to assess this option, the potential social and environmental effects also need to be considered. While the reservoir is impacted by severe droughts and has experienced some storage loss from sedimentation, most years it is generally full following spring snowmelt and precipitation upstream. Studies also indicate that considerable spillage occurs throughout many years in the dam‘s history, indicating the potential for capturing additional storage if the dam were ever raised. As indicated in previous sections in the Master Plan, the feasibility of using water from Dahla Dam for human consumption needs to be analyzed in depth, as it is currently assumed that water is unsafe for human consumption.

Based on initial observation, the data indicate preliminarily that the reservoir may present a sustainable source for water. Monthly flows in the Arghandab River above Dahla Dam (see Table 6) appear to far exceed water supply demand downstream. If the demand for water supply by year 2030 (Q_{ws} = 1.79 m^3/sec or 6,459 m^3/hr) is compared to the minimum average inflow into the reservoir (Q_{inflow} = 8.45 m^3/sec), it can be quickly determined that optimum level of water supply demand is potentially met throughout the year given adequate and constant storage. The irrigation demand and rate of evaporation and infiltration will need to be determined and considered in relation to the allocation of water for municipal supply.

Figure 12 shows a preliminary analysis of storage in Dahla Dam conducted by USACE. The irrigable area (y-axis) indicates the potential hectares of land that can be irrigated based on storage capacity of the dam. Since construction of the dam, the potential irrigable area has decreased due to sedimentation of the reservoir. The potential impact to irrigation after allocation for municipal and industrial use is indicated by the dashed red line. Impacts are also shown based on potential five-, eight-, and 18-meter dam raise scenarios. These water allocation scenarios were developed based on the water supply demand for a population of 1.2 million people at 120 lpcd, which corresponds to 142,098 m^3 / day, as developed for planning purposes of the Master Plan. Results of this analysis indicate a significant long-term water supply potential existing with this option under existing conditions at the reservoir.

Based on the analysis in Figure 12 a dam raise of five meters would also meet the demands of the city and increase the amount of water available for irrigation. Since there is also a demand for more irrigation water, an increase in storage capacity is preferable to reallocating the existing supplies. There are additional ways to optimize the water supply storage situation. For example, evidence suggests that siltation is a historical problem that will continue to affect water supply. Removal of silt would improve efficiency of the system and increase life span of the reservoir's storage.

Increasing efficiency of canal systems could also be used as a strategy to increase available amount of water from Dahla Dam reservoir for municipal supply. Using a liner in the main canals and secondary canals along with better timing of releases would improve the overall efficiency of the irrigation system, allowing additional water available for water supply. A more detailed assessment of the costs of such measures and benefits derived is recommended.

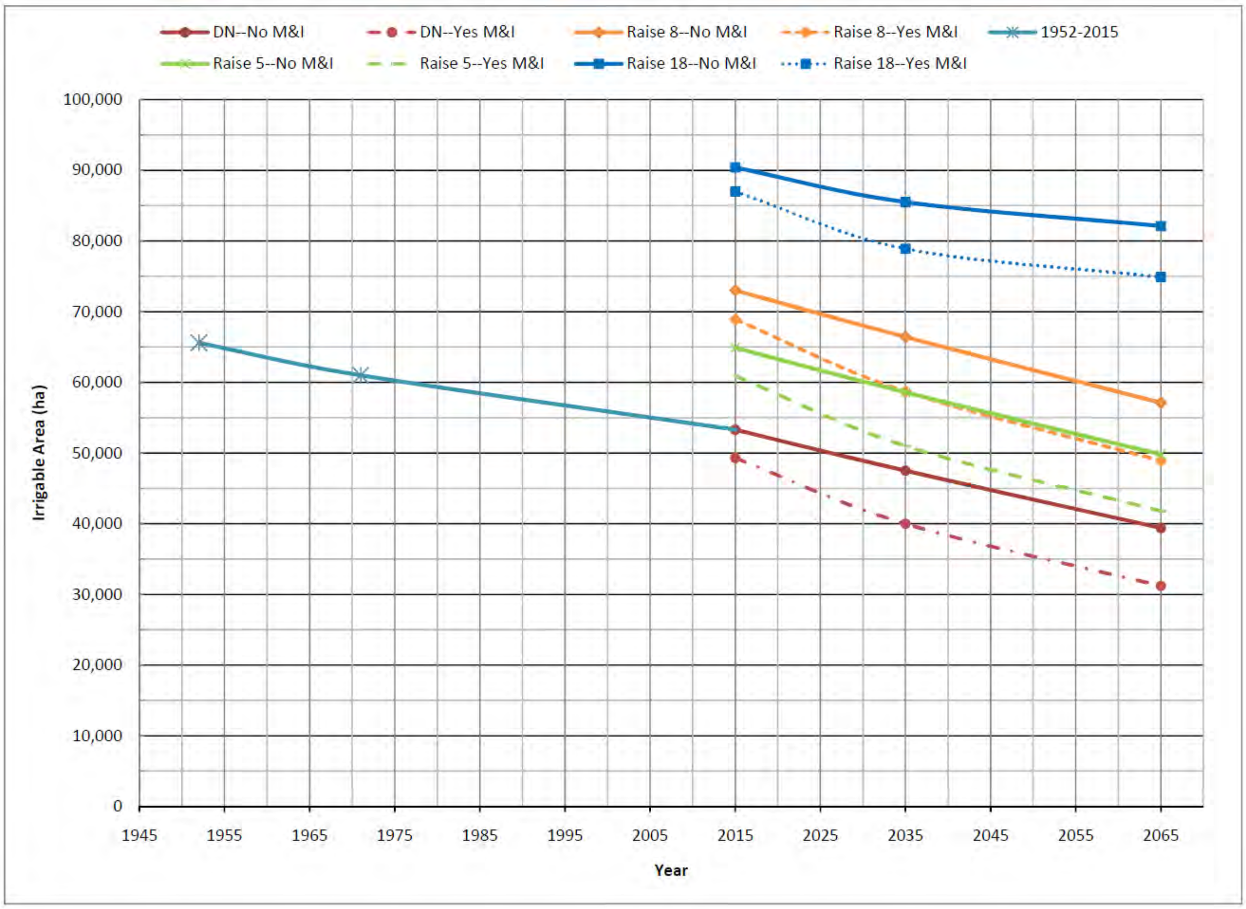


Figure 12. Impacts to Irrigation with Allocation for Municipal Water Supply

6.3 Water Treatment Options

Design of water storage, transmission, treatment, and distribution facilities depend on the quality of the water, volumes of water that must be processed, and the process by which water is received by the consumer. Water produced from the municipal wells and private wells in Kandahar City is currently not being treated. Surface water used for domestic purposes is also untreated. Under the current situation there are several options for providing residual disinfection for groundwater from the deep aquifer using chlorination. Currently, the full spectrum of contamination is unknown for the city aquifer. Without this information, that is to say without water quality samples from each well, what additional treatment may be needed to remove contaminants in the city aquifer cannot be determined. Consideration of the treatment process used on new sources of water supply will also be critical. Whether treatment occurs at the source, a distribution hub, or storage tank could affect the cost, real estate, and design needs in order to implement a project. The process used to treat the water will also play a role in the decision-making process used to decide where to treat.

The primary objective of water treatment is to protect public health. Surface water from rivers and lakes requires a certain level of treatment to make it potable and treatment processes are more complex because of the inherently higher levels of combined organic and inorganic contaminants. Groundwater is generally of better quality, however as this Master Plan has indicated the shallow aquifer in Kandahar City suffers from contamination due to infiltration of waste water. Of particular concern are reportedly high salinity levels observed in city wells.

Several groundwater and surface water treatment options were assessed for their use under an array of potential circumstances. Since the existing water supply situation is unacceptable the treatment method used on future water supplies must be considered in relation to cost, safety, local capacity, and overall practicability. This section addresses the following objective of the Master Plan.

- Identify the overall treatment, storage, and transmission components required to supply Kandahar City with a reliable water supply system.

6.3.1 Chlorination

Chlorine is added to water supplies to provide disinfection. Depending upon the water source and water quality disinfection may be all the treatment that is required. In its solid form it can be easily applied at the source, a distribution hub, or storage tank. In Kandahar City, AUWSSC (formerly CAWSS) has experience using this to periodically treat water at the two large reservoirs and wells that pump water directly to the distribution system.

Considering the potential water volumes associated with the development of a public water supply in Kandahar City, appropriate disinfection must be provided. Conservatively, based on an initial estimated concentration of 10 mg/L of chlorine added to the raw water for disinfection, a total daily demand of chlorine can be calculated and adjusted as the demand quantity of water increases. At relative large quantities, the practical method of chlorination is by way of gaseous chlorine.

Other chlorination compounds such as calcium hypochlorite can have an available chlorine supply equal to approximately 70% of the weight of the granules. For this project, that would require the hauling of over 200 kilograms of chlorine or high test hypochlorite (HTH) daily. On the other hand, liquid bleach (commercial grade, 12% sodium hypochlorite) could be used, but it would require a daily liquid transport of 1.4 to 1.5 kiloliters of commercial bleach. Liquid bleach will degrade with time and temperature. It can be stored for about 6 months at temperatures between around 10 and 20 degrees Celsius (50 and 70 degrees Fahrenheit). After this time, bleach will begin to degrade at a rate of 20% each year until totally degraded to salt and water. Storing at temperatures much higher than around 20 degrees Celsius could cause the bleach to lose its effectiveness and degrade more rapidly.

From an economic perspective based on material and hauling cost alone, it can be seen that gaseous chlorine provided in 907-kilogram containers is the practical agent to provide for disinfection for a large scale approach. Consideration for using chlorine bottles (68 kg) should be made if transportation hazards and other associated hazards associated with chlorine cylinders are too high. Generally, for an application this size, chlorine bottles are too small to be cost effective in that one bottle may be used daily. Security and safety hazards associated with the gaseous chlorine must be determined from accidental events, sabotage, and insurgent actions.

Depending on the selected agent for disinfection, different methods are required for injection. Gaseous chlorinators will require scales, evaporators, and regulators to inject the chlorine gas into the water flow. Liquid chlorine bleach requires neat and chemical feed pumps that can withdraw directly from chemical barrels or totes. Finally, dry chlorine powder such as HTH will require solution tanks, mixers, and chemical feed pumps.

Another potential alternative, especially if chlorination is done as a central operation would be the design and implementation of on-site chlorine generators. With a direct current (DC) power source, these units convert salt water to hypochlorous acid. This process is analogous to directly adding bleach or sodium hypochlorite. Generally, the largest unit available can produce up to 60 kg/day of chlorine equivalent, which can meet a daily load requirement. If the source water is generally a lower quality, it may require 150 kg of chlorine per day. The advantage of this type of on-site chlorine generator is the many safety features it offers when used as an alternative to chlorine gas systems. Transport and handling of chlorine cylinders is completely eliminated. Only saturated brine and softened water are needed for the ion generation process which safely and efficiently produces hypochlorite on-site. For this facility, it would be recommended that a minimum of two large units be provided. One of the drawbacks to these ion generator-type systems is that if the unit malfunctions or there is a power failure, no hypochlorite is produced. If the clearwell tank farm is a gravity feed and water flows via gravity, it is possible that non-chlorinated water can feed into the main supply line to the city.

Another option would be to add the chlorine at the zone hub tanks prior to the consumer ingestion. At the zone hub tanks, the chemical agent of choice may also change in that HTH becomes more cost effective and easy to execute. Eventually, if roof top tanks become the norm for the system, residents should or could be trained to add chlorine powder to their own tanks to ensure that the proper chlorine residual is maintained. However, chlorine would need to be added to the zone hub tank because of the activity associated with the standposts and potential backflow drainage into the distribution system.

On-site testing and monitoring for free chlorine can be performed using colorimetric methods similar to swimming pool equipment. An example of a colorimeter kit is in Appendix D.

<u>Chlorine (Solid)</u>

Pros

- Tablets or powder make for simple application.
- In solid form chlorine is relatively safe to handle.
- Could be added to any tank in the system or mixed and injected into the system.
- Local experience with application currently exists.
- Known to be commercially-available to Afghanistan.

Cons

- Significant costs are associated with treating large volumes of water due to transportation requirements.
- Logistically less efficient than chlorine gas.

Chlorine (Gas)

Pros
- Gaseous chlorine in pressurized steel containers is usually the most economical for disinfecting large volumes of water.
- Requires less transportation due to the high concentration of available chlorine.

Cons
- Local experience with application does not exist.
- Increased danger associated with handling and application.
- Due to complex application and hazardous potential, additional training is required than for solid form application.

6.3.2 Membrane Processes

As documented in several reports, groundwater in Kandahar City exhibits a relatively low quality and high TDS. Under these conditions, conventional water treatment (flocculation-sedimentation-sand filtration-disinfection) will not work optimally requiring that alternative treatment methods be considered. In the past, chlorination has been recommended as ―treatment,” but in reality chlorination is simply a disinfection process that may guarantee ridding of organisms carrying waterborne diseases but will not address other requirements for safe drinking water. If groundwater is not treated for other contaminants which chlorination does not remove (i.e. turbidity, hardness, phosphates, etc) the water may not be considered safe for drinking as per WHO standards. One important fact regarding chlorination alone is that by-products such as Trihalomethanes (THM) may be produced. THMs are carcinogenic by-products resulting from a chemical reaction between the chlorine and naturally occurring organic and inorganic compounds in water. There are several treatment methods that can simultaneously remove hardness, color, many kinds of viruses and bacteria and organic contaminants such as agricultural chemicals and THMs. The recommended ones for treating Kandahar groundwater are discussed in this section. The most popular treatments available are based on membrane or distillation technologies which mostly differ on cost-benefit associated with operating the plants. Distillation technology-based treatment plants are used in desalination process with high effluent production and having seawater as the feed, therefore not discussed in this document nor recommended for Kandahar City. Membrane based treatment processes present a viable option for treating Kandahar City contaminated groundwater. Available membrane based water treatment processes include Reverse Osmosis (RO), nanofiltration, ultrafiltration, microfiltration and electro-dialysis. Reverse Osmosis and nanofiltration are the recommended options for Kandahar City and are discussed in detail below.

Reverse Osmosis is probably the most popular membrane technology to use in desalination or treatment of brackish water and has the lowest production cost and energy consumption compared to other technologies. In RO, water is pressurized to pass through a membrane which rejects bacteria, pyrogens and normally 85% or more of inorganic solids. Organic solids are also rejected to a certain degree, depending on the molecular weight and the membrane matrix composition. Membranes manufactured for normal water treatment applications allow dissolved gasses to pass through. In general, the membranes are designed and manufactured to remove hardness, color, many kinds of bacteria and viruses, and organic contaminants such as agricultural chemicals and trihalomethane precursors. This ability to remove inorganic and organic compounds has made this technology very attractive for treatment of contaminated drinking water supplies. The biggest problem with RO is fouling and degrading of the membrane which requires continuous monitoring of the effluent quality. Degradation in effluent quality indicates membrane replacement. The reject or brine, is also a factor that needs to be dealt with during operation. In many countries, the reject effluent disposal is monitored and regulated as any industrial discharge. However, for Afghanistan, the environmental load of the rejected effluent may not be as significant as the existing runoff from agricultural areas and therefore not a determining factor for selection.

A similar technology that may be suitable for Kandahar City is nanofiltration. Although the operation of a nanofiltration system is similar to an RO system, the membrane is usually negatively charged which results in ion repulsion, a determining factor in salt rejection. Currently, there are several types of nanofiltration membranes available and their performance depends on the material and manufacturing process which corresponds to a specific application. The most popular applications for nanofiltration membranes are water softening and removal of various contaminants from drinking water including TDS, hardness, color, and agricultural chemicals. Since the membrane can determine the performance of the treatment system, special care has to be taken in designing a system that corresponds to the quality of the feed flow.

Finally, to produce high quality drinking water, the membrane-based treatments described above are normally combined with filtration with activated carbon filters and/or ion exchange resins. A partial list of contaminants with recommended treatment technologies (non-conventional) is presented in Table 18 below.

Table 18. Recommended Treatments for Several Contaminants

Available Water Treatment Technologies	Activated Carbon Filters (Granular)	Activated Carbon Filters (Solid Block or PreCoat)	Cation Exchange Softening	Distillation	Membrane Process - Reverse Osmosis - Nanofiltration
Contaminants					
Arsenic (0.05 mg/L)				X	X
Asbestos (10 pm/L)		X		X	X
Atrazine (0.003 mg/L)	X	X		*	X
Benzene (0.05 mg/L)		X		*	*
Fluoride (4.0 mg/L)				X	X
Lead (0.015 mg/L)		X	X	X	X
Mercury (0.002 mg/L)	X	X		X	X
Nitrate (10.0 mg/L)				X	X
Trichloroethylene (0.005 mg/L)	X	X		X	*
Total Trihalomethanes (0.10 mg/L)	X	X		X	*
Radium (20 pCi/L)			X	X	X
Radon (300 pCi/L)	X			*	*
Coliform bacteria (0 in 95% of samples)				X	*

Cryptosporidium parvum (Cysts)		X		X	X
Metallic taste (Iron, Manganese, Copper oxide, Sulfide)			X	X	X
Unpleasant taste	X	X		X	X
Turbidity (Looks cloudy)	X				*
Soap residue (Irritated skin, gray fabric, water marked surfaces)			X		
Scale buildup (Water heaters, plumbing)			X	X	X
Unpleasant odor (Chlorine & “Rotten eggs”)	X	X		X	X

* Not the best technology, marginal removal.

<u>Membranes Treatment Pros</u>

- Treatment process suitable to treat existing groundwater quality in Kandahar City.
- Scalable system that can treat small or large volumes of groundwater.
- System(s) can be installed at each existing municipal well location or at a centralized location.
- Produce high quality safe drinking water.

<u>Membranes Treatment Cons</u>

- Requires reliable power for production. Basically, no power, no water.
- Selection and design of process requires a full assessment of groundwater quality at each location considered.
- Skilled labor and continuous monitoring and quality testing of produced water are required.
- Controlled operation and maintenance.
- Equipment malfunction could result in extended periods of shutdown.
- Costs are much higher than conventional treatment, chlorination still required for removal of pathogens causing waterborne diseases not removed by the membrane.

6.3.3 Summary

The current water distribution system uses water from existing wells periodically stored in reservoirs and wells that pump water directly into the distribution system. There needs to be well head treatment or a centralized water treatment facility to utilize the existing well water. For well head treatment, there needs to be a chlorine facility and a clearwell to provide adequate chlorine contact time. Additionally, the well water will need treatment to remove the sulfates. Reverse Osmosis, distillation and ion-exchange processes could be used for this type of treatment.

For a centralized groundwater treatment facility, a 500-cubic meter clearwell would be required. The existing reservoirs are not adequate to use as clearwells unless baffles are added to the reservoirs. The pump discharges would need to be piped to the centralized treatment facility. All well water would be treated prior to entering the distribution network. The centralized treatment facility would not be recommended if there were head losses in the pipe to deliver water from the well to the treatment facility. This would decrease the well production, and the distribution system would need to be improved to get finished water back to the extraction pump proximity.

Membrane treatment methods pose multiple technical challenges in this environment, and a full assessment is recommended along with water quality analyses. Due to lack of water quality information for Dahla Dam and the Arghandab River, the needed level of treatment is unknown.

6.4 Water Distribution Options

The efficiency and reliability of the existing water supply system depends on maintaining a pressurized distribution system to avoid infiltration from the ground. Positive pressure prevents infiltration of groundwater which may be contaminated. This can only be achieved if elevated storage tanks are incorporated into the system or the pumps work continuously. The information available indicates that the distribution system is partially pressurized when the pumps are working. However, the intermittent electrical service suggests that the system is susceptible to infiltration of contaminated groundwater most of the time.

Potential water distribution options were identified using a combination of existing reports, professional experience, and input from the USACE PDT. The goal of this effort was to identify practical solutions which could later be considered in relation to the treatment and various source options previously discussed. This section addresses the following objective of the Master Plan:

- Identify the overall treatment, storage, and transmission components required to supply Kandahar City with a reliable water supply system.

6.4.1 Rehabilitate the Existing Distribution Network

Seventy percent of Kandahar City‘s existing water supply network is estimated to have problems with leaks. Estimates indicate that the current system contains approximately 167 km of piping. Of this, approximately 52 km were recently installed and assumed to be functioning better than the remaining portions. Other than knowing when the initial construction of the system began (1972) there is little to no information available about when various parts of the city received services. The existing infrastructure has aged and poor maintenance along with the effects of war has created these deficiencies.

The existing distribution system is undersized for a project of this magnitude. Pipes in need of increase in size are generally known, but until a source of water supply is identified, this will be an on-going assessment. In order to identify the condition of the system in a specific neighborhood, a reconnaissance-level approach would be a good first step. Spot-checking the system could provide valuable information about the condition and age of the system in that area which would help to make a decision about whether to move ahead with replacement or repair of areas with leaks and deficiencies. Once a reliable approach to rehabilitate the system has been identified, the system could be repaired incrementally as funding and time allow. It is possible that leaks would be beyond repair in many situations and require the installation of new piping.

Leak detection has proven in many cities to be well worth the expense in order to prevent the loss of limited drinking water. For the most part, these cities experience constant system pressure. The fact that the AUWSSC system is pressurized in several zones during the week for different times of day may be a limiting factor that will prevent the effective application of leak technology to this particular system. Because of the limited pressure applications in zones, a revision of the standard technique can be determined and adjustments made to make the leak detection program cost and benefit effective. Because of the amount of work and significant challenge that this effort would require, a pilot study could be the first step. This would also help determine and/or establish a local capacity to undertake this work in the future.

The paramount purpose of conducting a leakage pilot study is to determine if the specialized expertise that exists in the field of leak detection, especially in acoustic techniques application can provide a cost-effective and rapid diagnosis of undiscovered leaks in buried piping. Extreme building congestion, heavy traffic, narrow working areas, and dense population add to the complexity of finding, repairing, and working around the leakage points. The pilot study‘s goal is to show that this testing can effectively pinpoint leaks in a myriad of conditions such as narrow alleyways, concrete covered paths, extreme traffic conditions, and the limitation that the system is only pressurized for a limited number of hours per week.

This is why a ―pilot” approach is recommended as a beginning task for this option. This option is most likely an initial step that would be carried out in conjunction with other measures to improve the distribution system, such as upgrades or expansions.

The existing water distribution system should be limited for reuse in the hub zone distribution system. The waterlines that are to be reused should be limited to pipes that are 100 mm or greater in size. Distribution mains should be a minimum size of 100 mm to allow for adequate flow for peak future demands.

Hydraulic analysis of the existing distribution system was performed to evaluate system pressures and velocities under normal demands (20 lpcd) for the areas of coverage. Static pressures in the system range from 190 – 983 kPa. The minimum pressure required for filling zone hub tanks is 200 kPa. The existing water distribution system is not capable of providing water to the zone hub tanks at the minimum demand required for basic access levels of 20 lpcd due to negative pressures throughout the system, indicating that zone hub tanks cannot be filled. Due to pressure inadequacies, reported severe leakiness, and brittle pipe in the existing system, the most cost-effective long-term and reliable solution is to upgrade the system using all new pipes.

6.4.2 Upgrade and Expand Distribution Network

In order to assess how upgrades and expansions to the distribution network would look in Kandahar City, a modeling approach was employed. This water distribution model consists of two main goals: 1) computer model a new water supply system for Kandahar City and 2) model a water supply system to provide adequate capacity for expansion and growth of the city population. It was determined, since the existing pipe will be only be utilized for the hub zone distribution system, calibration is not necessary. The only information that could be gleaned from the calibration, in this circumstance, is a better estimation of the friction losses. This coefficient can be estimated based on pipe type and size.

The purpose of upgrading and expanding the distribution network is to develop a safe, reliable, and operable potable water system for Kandahar City utilizing the existing water system distribution piping and incorporating new water supplies. The purpose of computer modeling the Kandahar City water system is to provide a working dynamic model of the water system, determine if there are deficiencies in the distribution system and provide recommendations for improving the distribution system with water supplies from new sources, which at this point are assumed to be well fields and/or Dahla Dam Reservoir. The analysis of incorporating new supplies with hub zone water distribution system will determine the new water system sizing and connectivity to provide the entire system with suitable water at the minimum and maximum demands. The results of the water supply modeling provide a framework for assessing alternatives later.

The existing water distribution system is one pressure zone with existing wells that are directly connected to the water distribution system, or are connected through three ground elevation water storage tanks. There are no pressure reducing valves or isolation valves in the water system based on the Kandahar City Water Network and Population Distribution plans provided by USACE AED-S. However, the ICRC presentation documents indicated the locations of new waterlines and valve vaults in the Mir Wais Mina, Mir Bazaar and Old City areas of the city. The water distribution system is modeled as a single pressure system without the existing wells on the system. It is not necessary to include the wells in the computer water distribution model since the existing wells will not be used once a suitable source of water that complies with the WHO standards is available.

Based on the preliminary water supply scenarios that were modeled, the indication is that the hub zone distribution system can be incorporated to provide water for current residential areas and future expansions. Generally pipes will require increases in size from supplying the existing residential areas at 20 lpcd to supply future area expansion with a demand at the 120 lpcd level. The location where the water supply source connects to the distribution network will help determine a practical approach to sizing and pipe layout of the new water supply system. Similarly, the source location determines the pump size and capacities to supply water to the zone hub tank.

6.4.3 Clear Well / Main Storage Tank Facility

Initial analysis has identified large storage tanks as potentially needed and beneficial components of a future distribution scheme. Two tanks consisting of a capacity of 7.5 million liters each covered and reinforced with concrete would supply one day of storage at the 20 lpcd demand for the current population of 675,000 people. As part of the main tanks complex, all of the supporting structures and process facilities would be installed with the initial construction. This would include the disinfection system to supply residual chlorination for the piping network. To reduce system start up costs, a single main tank could be installed first. As demand and infrastructure is developed the second tank would be brought online.

It is important to note that the main storage tanks can be located wherever necessary to support a suitable source of water and still function as intended. The main influencing factor would be whether gravity could be fully used as opposed to pumps.

6.4.4 Zone Hub Tanks

Zone hubs are provided to assure sustainability can be provided by the local water authority by limiting the need for high rise equipment and to limit the losses due to higher pressures.

The city is divided into service zones to ensure an individual‘s carry distance does not exceed 1,000 meters as recommended by the WHO for a basic access service level (Howard & Bartram, 2003). These carry distance zones act as the delineation lines for the area that a zone hub tank would service. Hub tanks supply the pressure to the public standposts, act as a pressure control mechanism for the supply system, offer protections from one zone being able to draw all the water in the distribution system, and maintain a day‘s storage plus 20% for peak demand. This type of layout also offers the ability to boost chlorine levels via zone hub tanks, if required.

A suggested design criteria for these tanks is to enable them to store 120% of the total daily demand for each zone in accordance with USAID‘s Technical Note No. RWS. 5.D.3 (USAID, 1982). Ordinarily, a western-type system would require a half day‘s (50%) storage. When Kandahar‘s system is up and operating in the long term, the required capacity may be reduced to this value. However, the reliability of the system would be an unknown for some time after construction, and it is important that there will be enough reserve for system maintenance and malfunctions.

The water level in the zone hub tanks should be set to supply adequate pressure for the typical three-story building. Taller buildings would require roof top storage tanks and individually-owned booster pumps to meet pressure requirements. Also, it is recommended to maintain a residual pressure at the public standpost of between 10-30 m / 14.43 psi (Brikké & Bredero, 2003). Both of these qualifications should be met when considering the tank elevations and system pressure requirements.

6.4.5 Public Standposts

Public standposts are defined by the WHO as a location that ―distributes water from one or more taps to many users" (Brikké & Bredero, 2003). Since these types of facilities are utilized by many people, they are subject to quickly falling into disrepair. For this reason, they are fully encased in concrete with very limited access to the plumbing. This also makes it more difficult to make illegal above ground taps. As a further precaution for protecting the supply from being rapidly depleted by breaks or inadvertently leaving water running at the taps, a flow regulating valve and self-closing type faucet have been added. This flow regulating valve would limit the loss at the standpost to the setting at the valve.

Brikké and Bredero (2003) suggest that the zone hub tanks could be eliminated and simply connect all the public standposts to the mains. This would be problematic for an emerging system. As stated, the zone hub tanks serve several functions, key among them are dispersed city storage for each zone and reduced chance that one zone will draw down the entire system. For remote areas, it may make sense to use this type of connection where it would be difficult to serve from the centralized tanks. In these cases, extra precautions would need to be installed at the standpost.

Public standposts should be distributed throughout each zone along roads and alleys to give the greatest access to all residents at a spacing of no more than 300 meters. This type of distribution will also help to promote better maintenance due to its high visibility and public awareness. As a side effect of more convenient access to water, more water would be used. Excess consumption, that is to say an individual using more than 20 lpcd, may strain the network. This system is conceptually designed to supply a limited amount of water. If excess consumption becomes a problem, it will reduce the ability to equally distribute the limited water supply.

6.4.6 Roof top Tanks

Another option would be to add the chlorine at the zone hub tanks prior to consumer ingestion. At the zone hub tanks, the chemical agent of choice may also change in that HTH becomes more cost-effective and easy to execute. Eventually, if roof top tanks become the norm for the system, residents should or could be trained to add chlorine powder to their own tanks to ensure that the proper chlorine residual is maintained. However, chlorine would need to be added to the zone hub tank because of the activity associated with the standposts and potential backflow drainage into the distribution system. On-site testing and monitoring for free chlorine can be performed using colorimetric methods similar to swimming pool equipment. Colorimetric comparators can be purchased from many companies.

6.5 Alternative Formulation and Evaluation

A comprehensive water supply strategy involves identifying the overall water source capacities and water treatment, storage, and distribution requirements needed to supply water. The assessment of those components has resulted in a list of options that can be used to formulate the water supply alternatives to consider. Detailed water distribution analysis was used to aid the integration of various components and determine feasibility for implementation. Cost estimates of selected alternative(s) are presented in later sections. The following evaluation is based on the ability of the water supply options to meet near-term basic access needs of 20 lpcd, long-term optimum access needs of 120 lpcd, or both, which is consistent with project objectives. It is important to identify an alternative that can meet the immediate critical need but also be sustainable in the long-term, meeting the needs of the future population.

Alternatives, including the no action alternative, are also assessed based on their near-term (2012 – 2015), mid-term (2016 – 2020), and long-term (2021 and beyond) outcomes.

<u>Summary of Water Supply Options</u>

- Groundwater
  - Zone 1 (East of Kandahar City)
  - Zone 2 (North of Kandahar City)
  - Zone 4 (Existing Municipal Wells in Kandahar City)
- Surface Water
  - Dahla Dam

(Note: subsurface dams and sand dams may be assessed in more detail at a later date)

<u>Summary of Treatment Options</u>

- Chlorination
- Membrane Processes

<u>Summary of Distribution and Storage Options</u>

- Rehabilitation of Existing Distribution Network
- Upgrade and Expand Distribution Network
- Zone Hub Tanks
- Watering Standposts
- Roof top Tanks

6.5.1 Alternative 1: No Action

Currently, there is a combination of municipal wells and private wells that serve residents of Kandahar City. The present situation is considered to be problematic due to the unregulated drilling of wells, threats to health, depletion of the aquifer, and supply not meeting demand. The potential combined maximum water production is close to 300 l/s but only six out of the existing 15 wells are thought to be operational. This potential production is under ideal conditions and far from the current reality.

A variety of organizations have assisted with drilling of private wells for households without proper access to water. Estimates indicate that over 356 hand tube wells were installed and since drilling is not regulated, environmental impacts are unchecked. Concerns exist with over-extraction, contamination, and licensing. Reports indicate that an increase in private wells occurred as surface water supplies were depleted during the recent drought event, and aquifer levels severely declined as a result.

The use of private wells may be considered a "relief" to the acute water problem in the city, but in reality, the uncontrolled tapping into the existing aquifers results in health and safety hazards. First, the quality of the groundwater is not controlled and potentially hazardous and not suitable for human consumption. Secondly, the multiple holes in the ground are conduits for cross contamination of the aquifers. The proliferation of private wells creates a long-term health and safety problem. The following table depicts the municipal water supplies without project condition (i.e. no action) for maximum daily use (i.e. demand) and capacity. As shown in Table 19, the difference between projected average day water demand and production without a plan results in a deficit for the community over the time periods shown.

Table 19. M&I Water Production – Without Project Condition – Maximum Daily Use and Production Capacity

Projected average day water demand (m^3/day)	Time Period 2012 - 2015	2016 - 2020	2021 - 2025	2026 - 2030
Residential	87,300	99,752	115,640	134,058
Commercial	No data	No data	No data	No data
Industrial	No data	No data	No data	No data
Total	87,300	99,752	115,640	134,058
Average day water production capacity without a plan				
Zone 4 (municipal wells)	8,000	8,000	8,000	8,000
Total	8,000	8,000	8,000	8,000
Deficit or surplus between projected average day water demand and production capacity (m^3/day)	-79,300	-91,752	-107,640	-126,058

<u>Outcomes of Alternative 1 (No Action)</u>

- Near-term
    - Continued water deficit due to inability to supply 120 lpcd.
    - Continued health problems posed by consumption of groundwater beneath city.
    - Continued lack of equitable and shared access to water among various water user groups.
    - Increased risk of continued social instability and conflict.

- Mid- and Long-term
    - Continued water deficit due to inability to supply 120 lpcd.
    - Further vulnerability to drought.
    - Continued depletion of Zone 4 aquifer.
    - Increased lack of water access.
    - Increased risk of continued social instability and conflict.
    - Potentially severe health problems resulting from worsening of water quality in Zone 4.

No Action has been eliminated as an option because it fails to meet basic access levels and existing or future demand, is hazardous, and does not provide the majority of the population with access to water.

6.5.2 Alternative 2: Supply Kandahar City with 100% groundwater

Based on the results of the groundwater modeling, the following areas are either existing or potential sources with groundwater production:

- Zone 1 (East of Kandahar City)
- Zone 2 (North of Kandahar City)
- Zone 4 (Existing Municipal Wells in Kandahar City)

Based on results of the same modeling effort, the maximum sustainable withdrawal rate from the aquifer at each site is:

- Zone 1: 13,700 m^3 / day
- Zone 2: 9,000 m^3 / day
- Zone 4: 10,000 m^3 / day

These three groundwater sources will be fully developed under this alternative to provide maximum sustainable output of groundwater resources. The total maximum withdrawal rate is 32,700 m^3 / day. Assuming full production is met by 2015, it is equivalent to serving the 2015 population of 760,000 at a rate of about 43 lpcd and the projected future population of 1.2 million in 2030 at a rate of about 27 lpcd. This alternative clearly does not meet the long-term demand of the population by providing an optimal level of service of 120 lpcd.

Table 20 depicts the municipal water supplies without project condition (i.e. no action) for maximum daily use and capacity. As shown, the difference between projected average day water use and supply without a plan results in a deficit for the community over the time periods shown. Due to the remaining water deficit the most likely scenario is to develop all groundwater options.

Table 20. M&I Water Production – 100% Groundwater Development – Maximum Daily Use and Production Capacity

Projected average day water demand (m^3/day)	Time Period 2012 - 2015	2016 - 2020	2021 - 2025	2026 - 2030
Residential	87,300	99,752	115,640	134,058
Total	87,300	99,752	115,640	134,058
Average day water production capacity with groundwater only				
Municipal wells (Zone 4)	10,000	10,000	10,000	10,000
Zone 1 (east of KC)	13,700	13,700	13,700	13,700
Zone 2 (northwest of KC)	9,000	9,000	9,000	9,000
Total	32,700	32,700	32,700	32,700
Deficit or surplus between projected average day water demand and production capacity (m^3/day)	-54,600	-67,052	-82,940	-101,358

The alignment for the transmission pipeline for Zones 1 and 2 is shown in Figure 13. After discussion with the PDT the Zone 1 alignment was chosen because it follows the major highway entering Kandahar City where it can connect to the distribution system at the east end of town. The most practical Zone 2 alignment was to run the transmission pipe along the canal through the mountains where it can connect to the distribution system on the west end of town. The pipeline from Zone 1 is approximately 18 km and the pipeline from Zone 2 is approximately 4 km.

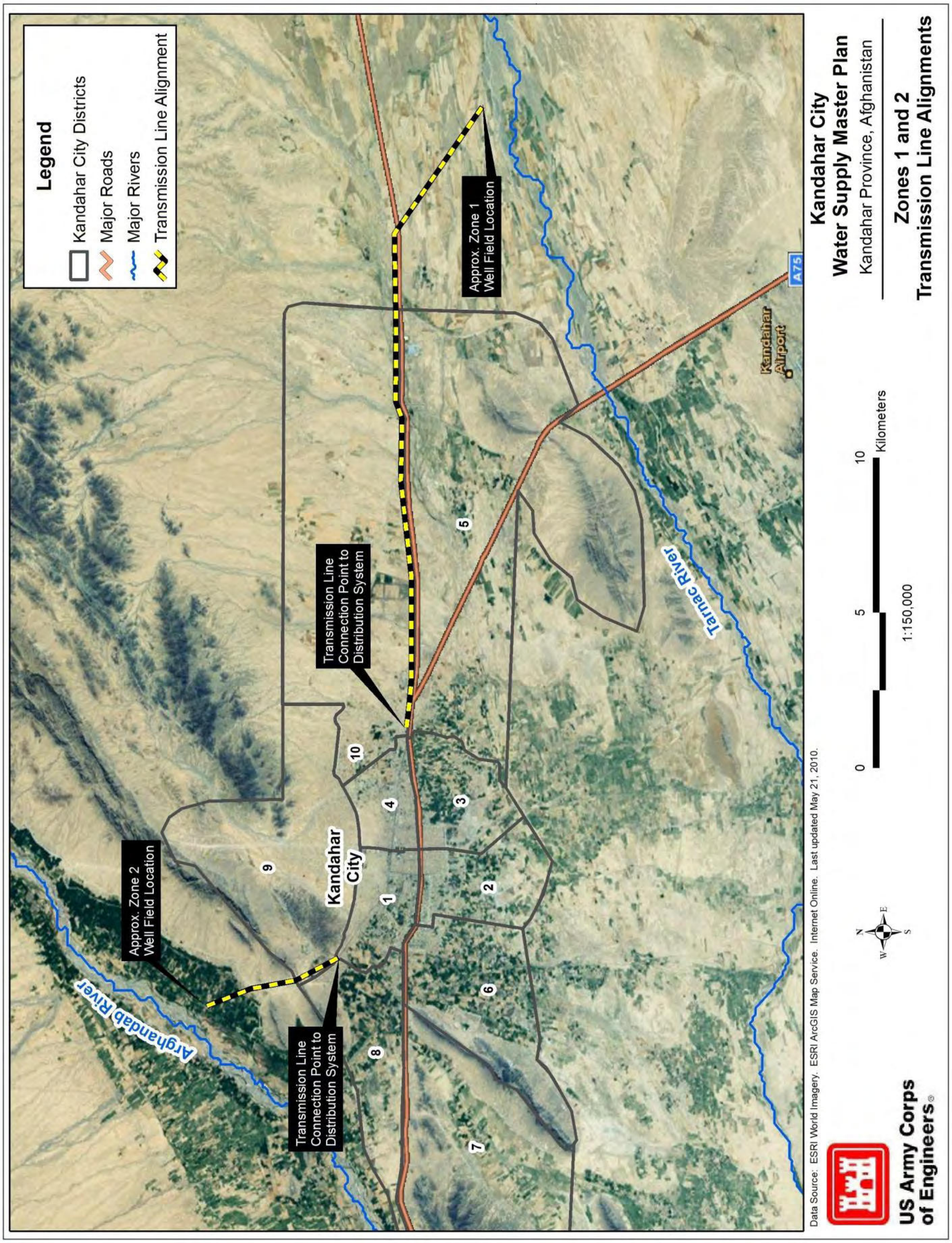


Figure 13. Zones 1 and 2 Transmission Line Alignments

The distribution system under this alternative should be initially constructed using new pipes in the existing areas of the city that are currently served and then expanded to areas of the city not currently served. As well fields are developed and the transmission pipelines are constructed and connected, the system will continue to be upgraded. Since the maximum volume of water provided to the city will not reach 120 lpcd, to save costs, the pipe sizes would not need to be sized based on the 120 lpcd design criteria previously recommended. Initially, public standposts can be constructed in areas with highest need and water supply trucks can fill the tanks with water from the well field. Later, as zone hub tanks are built, the standposts can be connected to the system.

In terms of water quantity, the service level for this alternative does meet basic access criteria as stated by the WHO. However, water quality may fail to meet that same classification. As previous tests on wells open to the unconfined, upper confined, and city aquifer have shown, the average total dissolved solid levels are around 815 mg/L. Concerns about unacceptable biological contaminants in Zone 4 have also been raised throughout this Master Plan. Until the wastewater issues in Kandahar City are resolved, the city aquifer will continue to pose a risk to human health and the environment. Also, the treatment methods required to remove suspended solids and biological contaminants are not recommended as solutions to treat water in Zone 4. Water quality testing is recommended as an initial step in Zone 4. Groundwater quality in Zone 2 is expected to be good (TDS < 500 mg/L) but testing is recommend here as well. Testing to verify the assumed good water quality from the deep aquifer in Zone 1 is also recommended.

Outcomes of Alternative 2

- Near-term
  - Provides 43 lpcd by 2015, but water deficit remains.
  - Improved situation in near-term but water deficit remains.
  - Continued health problems posed by consumption of groundwater beneath the city.
  - Continued lack of equitable and shared access to water among various water user groups.
  - Reduced risk of continued social instability and conflict.

- Mid- and Long-term
  - Continued water deficit due to inability to supply 120 lpcd. Provides 37 lpcd by 2020, and 27 lpcd to 2030 population.
  - Further vulnerability to drought.
  - As population growth continues the potential for groundwater depletion in Zones 1 and 2 is high as supply attempts to keep up with rising demand.
  - Continued depletion of Zone 4 aquifer.
  - Increased and continued lack of water access in new growth areas along the periphery of the city.
  - Increased risk of continued social instability and conflict.

6.5.3 Alternative 3: Supply Kandahar City with a combination of groundwater and surface water

This alternative considers potential for a combination of both surface water and groundwater to supply Kandahar City. The purpose of this alternative is to see what the outcomes are of supplying the city with the best combination of both groundwater and surface water in an effort to meet the long-term demand.

Based on the results of the groundwater modeling, the following areas are either existing or potential sources with groundwater production:

- Zone 1 (East of Kandahar City)
  - Zone 1 is recommended under this alternative because the deep aquifer at this location is less susceptible to drought and seasonal climate variation, and is thought to be the most dependable source by the USACE PDT. This source also meets the basic access level demand for the existing population of 20 lpcd.

- Zone 2 (North of Kandahar City)
  - Zone 2 is not recommended under this alternative because the shallow aquifer in this location is more vulnerable to depletions resulting from drought and low flows in the Arghandab River. Additionally this source does not meet the basic access level demand for the existing population.

- Zone 4 (Existing Municipal Wells in Kandahar City)
  - Zone 4 is recommended because it is the quickest option for supplying the population with water. However, because of water quality concerns and the potential impacts of drawdown in the city aquifer this option would most likely be abandoned once other options are made available.

The following groundwater development is recommended as the most likely scenario for this alternative and the pumping rates are:

- Zone 1: 13,700 m^3 / day near-term and long-term
- Zone 4: 10,000 m^3 / day near-term only

Based on the assessment of surface water options the Dahla Dam reservoir is the best option for municipal water supply because of its ability to meet the long-term demand. Based on discussions with the USACE PDT, it is assumed that the treatment facility and transmission pipeline needed to connect the reservoir supply with the city would not be operational until after 2015. It was previously determined that the reservoir has the potential to meet the long-term demand of the city's 2030 population, however since groundwater from Zone 1 will also be supplying the city the required volume from the reservoir is approximately:

- Dahla Dam reservoir: 128,300 m^3 / day mid-term

Table 21 depicts the most likely alternative involving groundwater and surface water and shows the difference between daily usage and available municipal groundwater and surface water supplies. As shown, under this alternative the difference between projected average day water use and supply results in a deficit for the community in the near-term but in the mid- and long-term periods the full demand is met. The most likely groundwater and surface water development option maximizes the ability to quickly supply residents with water and minimizes investment in groundwater in anticipation of the Dahla Dam supply.

Table 21. M&I Water Production – Most Likely Groundwater and Surface Water Development – Maximum Daily Use and Production Capacity

Projected average day water demand (m3/day)	Time Period 2012 - 2015	2016 - 2020	2021 - 2025	2026 - 2030
Residential	87,300	99,752	115,640	134,058
Total	87,300	99,752	115,640	134,058
Average day water production capacity with all groundwater and surface water				
Municipal wells (Zone 4)	10,000	0	0	0
Zone 1 (east of KC)	13,700	13,700	13,700	13,700
Dahla Dam	0	96,225	128,300	128,300
Total	23,700	109,925	142,000	142,000
Deficit or surplus between projected average day water demand and production capacity (m^3/day)	-63,600	10,173	26,360	7,942

The distribution system under this alternative will initially be constructed in areas of the city not currently served. Pipe sizes should be installed in anticipation of the entire system being pressurized and sized to provide 120 lpcd. Initially, public standposts can be constructed in areas most in need and water supply trucks can be used to transport water from well fields to public standposts in the city. Later as zone hub tanks are built, the standposts can be connected to the system.

The transmission pipeline from the dam would be built to its ultimate capacity immediately, but it is assumed the water treatment plant would be built in three increments as demand increases over time. Naturally the treatment plant would be built to meet the necessary 120 lpcd level of service as quickly as possible. To be conservative, it is assumed that the dam raise, first increment of the treatment plant, and transmission pipeline will not be operational, supplying water to the city, until after 2016. Therefore, groundwater is likely to be the sole source of water until around 2016, at which point surface water and groundwater will both supply the city.

<u>Outcomes of Alternative 3</u>

- Near-term
  - Provides 31 lpcd by 2015 but water deficit remains.
  - Continued health problems posed by consumption of groundwater from city aquifer.
  - Continued lack of equitable and shared access to water among various water user groups.
  - Reduced risk of continued social instability and conflict.

- Mid- and Long-term
  - Supply of 120 lpcd is provided within 150 m of population.
  - Reduced vulnerability to drought.
  - Sustainable supply from Dahla Dam reduces risk of excessive pumping and aquifer drawdown in Zone 1.
  - Discontinued need of Zone 4 to supplement supply.
  - Water access is provided in new growth areas along the periphery of the city.

- Reduced risk of social instability and conflict.

6.5.4 Alternative 4: Supply Kandahar City with groundwater first, then surface water only

This alternative considers potential for a combination of both surface water and groundwater to supply Kandahar City. The purpose of this alternative is to see what the outcomes are of supplying the city with the best combination of groundwater in the near-term and surface water only in the long-term. Based on the capacity of the Dahla Dam reservoir to supply the water in the long-term and near-term groundwater options, there may be an opportunity to utilize groundwater to meet immediate need and surface water to meet long-term need.

Based on the results of the groundwater modeling, the following areas are either existing or potential sources with groundwater production:

- Zone 1 (East of Kandahar City)
  - Zone 1 is recommended under this alternative because the deep aquifer at this location is less susceptible to drought and seasonal climate variation, and is thought to be the most dependable source by the USACE PDT. This source also meets the basic access level demand for the existing population of 20 lpcd.

- Zone 2 (North of Kandahar City)
  - Zone 2 is not recommended under this alternative because the shallow aquifer in this location is more vulnerable to depletions resulting from drought and low flows in the Arghandab River. Additionally this source does not meet the basic access level demand for the existing population.

- Zone 4 (Existing Municipal Wells in Kandahar City)
  - Zone 4 is recommended because it is the quickest option for supplying the population with water. However, because of water quality concerns and the potential impacts of drawdown in the city aquifer this option would most likely be abandoned once other options are made available.

The following groundwater development is recommended as the most likely scenario for this alternative and their pumping rates are:

- Zone 1: 13,700 m^3 / day near-term and long-term
- Zone 4: 10,000 m^3 / day near-term only

Based on the assessment of surface water options the Dahla Dam reservoir is the best option for municipal water supply because of its ability to meet the long-term demand. Based on discussions with the USACE PDT, it is assumed that the treatment facility and transmission pipeline needed to connect the reservoir supply with the city would not be operational until after 2015. It was previously determined that the reservoir has the potential to meet the long-term demand of the city‘s 2030 population, which is approximately:

- Dahla Dam reservoir: 142,000 m^3 / day

Table 22 depicts the most likely alternative using groundwater as an initial source of water and surface water only as a long-term source and shows the difference between daily usage and available municipal groundwater and surface water supplies. As shown, under this alternative the difference between projected average day water use and supply results in a deficit for the community in the near-term but in the mid- and long-term periods the full demand is met. The most likely groundwater and surface water development option maximizes the ability to quickly supply residents with water and minimizes investment in groundwater once water is supplied from the reservoir. It is assumed that Zone 1 will become a backup source of water for the city when water is supplied from the reservoir.

Table 22. M&I Water Production – Most Likely Groundwater First then All Surface Water Development – Maximum Daily Use and Production Capacity

Projected average day water demand (m^3/day)	Time Period			
	2012 - 2015	2016 - 2020	2021 - 2025	2026 - 2030
Residential	87,300	99,752	115,640	134058
Total	87,300	99,752	115,640	134058
Average day water production capacity with groundwater initially then surface water				
Municipal wells (Zone 4)	10,000	0	0	0
Zone 1 (east of KC)	13,700	0	0	0
Dahla Dam	0	106,500	142,000	142,000
Total	23,700	106,500	142,000	142,000
Deficit or surplus between projected average day water demand and production capacity (m^3/day)	-63,600	6,748	26,360	7,942

The distribution system under this alternative should be initially repaired and then expanded to areas of the city not currently served. As well fields are developed and the transmission pipelines are constructed and connected, the system will continue to be upgraded. Pipe sizes should be installed in anticipation of the entire system being pressurized and sized to provide 120 lpcd. Initially, public standposts can be constructed in areas with highest need and water supply trucks can fill the tanks with water from the well field. Later, as zone hub tanks are built, the standposts can be connected to the system. New public standposts and zone hub tanks can be designed and constructed to make the system operate efficiently to provide water at a rate of 38 lpcd initially, then 120 lpcd long-term. Ultimately, the system should provide a public standpost within 150 m of every household.

Outcomes of Alternative 4

- Near-term
    - Improved situation in near-term but water deficit remains.
    - Continued health problems posed by consumption of groundwater from city aquifer.
    - Improved access to water among various water user groups.
    - Reduced risk of continued social instability and conflict.

- Mid- and Long-term
    - Supply of 120 lpcd is provided to entire population.
    - Reduced vulnerability to drought.

- Sustainable supply from Dahla Dam reduces risk of excessive pumping and aquifer drawdown in Zones 1 and 4.
- Discontinued need of Zones 1 and 4 to supplement supply.
- Zone 1 becomes back-up.
- Water access is provided in new growth areas along the periphery of the city.
- Reduced risk of social instability and conflict.

6.5.5 Conclusion

- Based on stated outcomes of Alternative 1 (No Action), the project objectives are not met.

- Based on stated outcomes of Alternative 2 (Supply Kandahar City with 100% groundwater), the project objectives are not met.

- Based on stated outcomes of Alternatives 3 and 4, both of these alternatives meet the project objectives. Either one of these alternatives is acceptable based on their ability to meet both near-term basic access needs and long-term optimum access needs.

6.6 Cost Estimate

6.6.1 Methodology / Assumptions

Cost estimates presented in this section are intended to provide a conceptual level of cost information for the recommended plan. They are considered to be a 10 percent-level of detail, which is consistent with the project scope of this portion of the Master Plan. Cost estimates were developed using storage tank designs, distribution network pipe size upgrades, other infrastructure, information provided by AED-S and construction methods recommended in this document. Local labor rates were applied wherever possible. Security estimates were used in order to determine the need for contractor security. Well rehabilitation and drilling estimates are based on USACE experience in Afghanistan working with contractors. To achieve more detailed cost estimates, further information on design and construction activities is required.

6.6.2 Rehabilitate Zone 4 Wells

Based on the assessment of boring logs and existing information by the USACE PDT recommendations were made on the level of effort that may be required to make the wells at each site operational. Rehabilitation activities consist of verifying existing well and pump performance, reconstructing wells, and replacing old wells with new ones. In some cases a low-end cost and high-end cost estimate were prepared. Each well was given a rating which indicates the most likely potential repair. Level 1 effort includes verifying the well and pump performance. Level 2 effort includes making replacements and repairs. Level 3 effort includes well replacement and atonement. Table 23 shows the estimate to repair or replace the municipal wells in Zone 4. Table 24 shows the operation and maintenance estimate for Zone 4.

Table 23. Estimated Repair or Replacement Costs of Municipal Wells

Well Name/Location	AED-S Designation	Estimated Depth (m)	Level of Effort	Estimated Cost ($)
Mechanic School	1	62	Level 2	$ 118,000
East of CAWSS	2	90	Levels 2 and 3	$118000 or $459000
South of CAWSS, No 1	3	90	Levels 2 and 3	$118000 or $459000
Fazal Kandari School	4	90	Levels 2 and 3	$118000 or $459000
Small Reservoir	5	87	Level 1	$ 74,000
Old Eid Gah	6	110	Level 3	$ 341,000
Power Station Compound	7	145	No further action if not to be used for local or network water supply.	$ -
ARCS Clinic Compound	8	100	Level 1	$ 74,000
Commando Compound	9	60	Level 3	$ 341,000
Mir Wais Lycee	10	132	Levels 2 and 3	$118000 or $459000
South of CAWSS, No 2	11	131	Level 1	$ 74,000
Ahmad Shah Baba Lycee	11a	145	Level 1	$ 74,000
Mah Bas Prison	12	108	Level 1	$ 74,000
Mirza Mohmmed Qalacha	13	80	Levels 2 and 3	$118000 or $459000
Quli Urdu No 1	14	80	No further action if not to be used for local or network water supply.	$ -
Quli Urdu No 2	15	80	No further action if not to be used for local or network water supply.	$ -
CAWSS TW1	0	96	Level 2	$ 118,000
CAWSS TW2	0	95	Level 2	$ 118,000
Sadat Ghundai	0	67	Level 2	$ 118,000
Lowi Walla TW4	0	94	Level 2	$ 118,000
Aino Primary School	0	101	Level 2	$ 118,000

Low End Total Estimate for all Zone 4 Wells	**$**	**2,290,000**
High End Total Estimate for all Zone 4 Wells	**$**	**3,870,000**

Notes/Assumptions

1 Assumes a 100 m depth for all replacement wells

2 Does not include possible security costs

3 Level 2 effort assumes wells in question will not have to be replaced (low-end costs)

4 Level 3 effort assumes inspection results show wells need to be replaced (high-end costs)

Table 24. Zone 4 O & M Costs

Zone 4 O&M	Unit Cost	Quantity	Daily Total
Treatment (chlorine tablets)	$ 627	1	$ 627
Fuel consumption/generator	$ 960	18	$ 17,280
Labor	$ 120	12	$ 1,440
		Total	$ 19,347

Notes/Assumptions
1 18 generators operating 50% of time
2 Diesel gas is $2.50/liter
3 Generator consumes fuel at 32 liters/hour
4 Chlorine tablet usage 55 kg/day at full production in Zone 4
5 Chlorine costs are estimated to be $11.40/kg
6 Labor assumes 12 staff, 8 hrs/day, $15/hr

6.6.3 Develop Well Field in Zone 1

Table 25 shows the construction costs and Table 26 shows the operation and maintenance costs for Zone 1.

Table 25. Zone 1 Costs (Construction)

Zone 1 Development Cost	Unit Cost	Quantity	Total
Test wells at Zone 1	$ 1,200,000	3	$ 3,600,000
Wells in Zone 1	$ 1,200,000	26	$ 31,200,000
Clearwell tanks	$ 2,500,000	2	$ 5,000,000
Booster Pumps	$ 136,000	3	$ 408,000
Generators	$ 43,000	3	$ 129,000
Transmission pipeline from Zone 1	$ 38,000,000	1	$ 38,000,000
		Total	$78,337,000

Notes/Assumptions
1 Well unit costs include generator and pumps
2 Transmission line cost estimate based on 18-km line
3 Real estate costs not shown (unknown)

Table 26. Zone 1 O & M Costs

Zone 1 O&M	Unit Cost	Quantity	Daily Total
Treatment (chlorine tablets)	$ 855	1	$ 855
Fuel consumption/generator (booster pumps)	$ 960	2	$ 1,920
Fuel consumption/generator (well pumps)	$ 960	26	$ 24,960
Labor	$ 120	4	$ 480
		Daily O&M Total	$ 28,215

Notes/Assumptions

1 Two generators operating 50% of time

2 Diesel gas is $2.50/liter

3 Generator consumes fuel at 32 liters/hour

4 Chlorine tablet usage 75 kg/day at full production in Zone 1

5 Chlorine costs are estimated to be $11.40/kg

6 Labor assumes 4 staff, 8 hrs/day, $15/hr

6.6.4 Develop Well Field in Zone 2

Table 27 shows the construction costs and Table 28 shows the operation and maintenance costs for Zone 2.

Table 27. Zone 2 Costs (Construction)

Zone 2 Development Cost	Unit Cost	Quantity	Total
Test wells at Zone 2	$ 300,000	3	$ 900,000
Wells in Zone 2	$ 300,000	12	$ 3,600,000
Clearwell tanks	$ 2,500,000	2	$ 5,000,000
Booster Pumps	$ 136,000	3	$ 408,000
Generators	$ 43,000	3	$ 129,000
Transmission pipeline from Zone 2	$ 20,000,000	1	$ 20,000,000
		Total	$ 30,037,000

Notes/Assumptions

1 Well unit costs include generator and pumps

2 Transmission line cost estimate based on 4-km line

3 Real estate costs not shown (unknown)

Table 28. Zone 2 O & M Costs

Zone 2 O&M	Unit Cost	Quantity	Daily Total
Treatment (chlorine tablets)	$ 570	1	$ 570
Fuel consumption/generator (booster pumps)	$ 960	1	$ 960
Fuel consumption/generator (well pumps)	$ 960	12	$ 11,520
Labor	$ 120	4	$ 480
		Daily O&M Total	$ 13,530

Notes/Assumptions

1 Two generators operating 50% of time

2 Diesel gas is $2.50/liter

3 Generator consumes fuel at 32 liters/hour

4 Chlorine tablet usage 50 kg/day at full production in Zone 2

5 Chlorine costs are estimated to be $11.40/kg

6 Labor assumes 4 staff, 8 hrs/day, $15/hr

6.6.5 Tanker Truck Costs

Table 29 shows the estimate for filling one public standpost with a tanker truck.

Table 29. Tanker Truck Costs

Cost to Fill Public Standpost	Unit Cost	Units	Total
Price to fill one standpost with tanker truck	$ 325.00	1	$ 325
		Total	$ 325

Notes/Assumptions

1 Cost shown is for filling one 20,000 liter storage tank; typical truck size is 8,000 liters

2 Assumes 2.5 trips to fill one tank

3 Cost per load of water is $130 (includes labor)

4 Estimate will vary depending on where water is being hauled from

6.6.6 Surface Water Supply Costs

As noted previously, the Dahla Dam reservoir contains enough water to meet long-term demand, therefore no costs for increasing storage capacity are considered. However if storage capacity is not increased it is assumed that water currently used from the reservoir for agricultural purposes must be reallocated for municipal purposes. The lost agricultural income associated with such a reallocation of use will be significant to the local farming economy. A dam raise to increase storage capacity would potentially offset those costs and is being assessed in a separate study. Table 30 shows the costs associated with a transmission pipeline from the reservoir and estimates costs for a treatment plan located in Kandahar City.

Table 30. Surface Water Supply Costs

Dahla Dam Water Supply Costs	Cost	Quantity	Total
Transmission pipeline from dam	$ 60,000,000	1	$ 60,000,000
First increment of treatment plant (50%)	$ 15,000,000	1	$ 15,000,000
Second increment of treatment plant (75%)	$ 7,000,000	1	$ 7,000,000
Third increment of treatment plant (100%)	$ 5,000,000	1	$ 5,000,000
		Total	$ 87,000,000

Notes/Assumptions
1 This information is based on preliminary estimates
2 Costs do not include the cost of lost agricultural income from reallocation of water to municipal use
3 O&M costs (not shown) are assumed to be $5,000 per day

6.6.7 Distribution Network and Storage Costs

Table 31 shows costs for constructing the distribution system, based on a phased approach.

Table 31. Distribution Network and Storage Costs

Distribution Network and Storage Costs				
Phase	**Component**	**Units**	**Unit Cost**	**TOTAL**
1 / Near - term	New Distribution Lines (Source to Hub Tank)	(NA)	(NA)	$ 47,000,000
	Pressure Reducing Valves	(NA)	(NA)	$ 5,000,000
	Valves	(NA)	(NA)	$ 3,000,000
	Zone Hub Tanks	27	$ 2,000,000	$ 54,000,000
	Normal Density Stand Posts	620	$ 250,000	$ 155,000,000
	Normal Density Stand Posts w/tanks	200	$ 380,000	$ 76,000,000
	High Density Watering Posts	400	$ 340,000	$ 136,000,000
	New Distribution Lines (Hub Tank to Standpost)	27	$ 12,000,000	$ 324,000,000
			Total	$ 800,000,000
2 / Mid - term	New Distribution Lines (Source to Hub Tank)	(NA)	(NA)	$ 24,000,000
	Pressure Reducing Valves	(NA)	(NA)	$ 800,000
	Valves	(NA)	(NA)	$ 2,000,000
	Zone Hub Tanks	19	$ 2,000,000	$ 36,000,000
	Normal Density Stand Posts	500	$ 250,000	$ 125,000,000
	New Distribution Lines (Hub Tank to Standpost)	19	$ 12,000,000	$ 228,000,000
			Total	$ 415,800,000
3 / Long - term	New Distribution Lines (Source to Hub Tank)	(NA)	(NA)	$ 47,000,000
	Pressure Reducing Valves	(NA)	(NA)	$ 13,000,000
	Valves	(NA)	(NA)	$ 4,000,000
	Zone Hub Tanks	27	$ 2,000,000	$ 54,000,000
	Normal Density Stand Posts	1620	$ 250,000	$ 405,000,000
	New Distribution Lines (Hub Tank to Standpost)	27	$ 12,000,000	$ 324,000,000
			Total	$ 800,000,000

Notes/Assumptions
1 The first 200 normal density stand posts will have tanks
2 Pipe sizes and quantities from Appendix C were used

6.7 Least-Cost Analysis

Using the cost estimates from the previous section a least-cost analysis was prepared for the remaining alternatives. This analysis was constrained by time and data gaps.

As previously mentioned, Alternative 2 does not meet the project objectives and Alternatives 3 and 4 both meet the objectives. Under both scenarios, Dahla Dam will supply large quantities of treated water in the long-term, and the main difference between the two alternatives is that Alternative 3 uses groundwater as a long-term supply source connected to the distribution network and Alternative 4 utilizes groundwater as a back-up source. Because the water supply source from Dahla Dam does not utilize pumps the cost of operation and maintenance is reduced. However, the cost of operation and maintenance estimated for all alternatives is rough, and needs to be investigated further.

The costs of implementation for the project include all costs associated with the project, such as development costs, real estate costs, and operation and maintenance, and monitoring costs. For this study estimation of costs was performed at the 10 percent level. For example, real estate costs were not estimated and operation and maintenance costs are difficult to estimate. The stream of costs associated with the project occurs at various points in time. Therefore, all costs were present-valued to the beginning of the period of analysis, and amortized at the FY11 federal discount rate of 4.125 percent over the 50-year period of analysis, to develop equivalent average annual costs.

For determining the economic cost of the project and its various components, a calculation is made to determine the cost of interest during construction (IDC). IDC is added to the other costs of the project, and included as part of the average annual cost. The IDC is included as an economic cost, but it is not included as a financial cost. IDC is calculated using the FY11 discount rate of 4.125 percent for costs incurred during construction of the project.

Table 32 shows the annualized water supply costs for the project alternatives assessed. Based on the analysis shown the least-cost alternative is Alternative 4, supplying groundwater first, then surface water with groundwater being a backup source. The average annual cost of Alternative 4 is approximately $89,531,596, however approximately $76,000,000 of this cost each year is associated with the distribution network construction costs. If operation and maintenance costs associated with treatment and the supply line between Dahla Dam and Kandahar City are greater than the estimated $5,000 per day, then this alternative could be more expensive. Additionally, costs of this alternative neither account for future improvements to the storage capacity of the reservoir nor lost income in the farming sector due to reallocation of storage. If applicable, inclusion of these costs would also increase the average annual cost of this alternative. Since project objectives are not met without a supply from the Dahla Dam reservoir Alternative 4 would still be the preferred alternative, and is therefore the recommended plan.

Table 32. Annualized Costs by Alternative

	Annualized cost (in thousands of dollars)	Projected average day water production (m3/day) - Time Period			
		2012 - 2015	2016 - 2020	2021 - 2025	2026-2030
Alternative 2 (100% GW)*	$ 103,503,485	32,700	32,700	32,700	32,700
Alternative 3 (GW and SW)	$ 94,534,389	23,700	109,925	142,000	142,000
Alternative 4 (GW first, then SW as backup)	$ 89,531,596	23,700	106,500	142,000	142,000

*Alternative 2 does not meet the long-term demand by a factor of approximately 4.3. While the ability to increase groundwater development does not exist, based on the cost of the development occurring in it would take an additional $73,000,000 of average annual costs to meet the demand using groundwater for a total average annual cost of $176,503,485 to meet long-term demand.

7.0 RECOMMENDED PLAN

7.1 Outcomes of Recommended Plan

The Recommended Plan is *Alternative #4: Supply Kandahar City with groundwater first, then surface water only.*

Near-term outcomes (2012 – 2015)*:

- Approximately 75% of the city served about 40 lpcd.
- Approximately 75% of the population is within either 150 m or 400 m of a watering point.
- Optimal water quality from Zone 1 but still questionable coming from Zone 4.

Mid-term outcomes (2016 – 2020):

- Approximately 100% of the city (881,000 people in year 2020) served about 120 lpcd.
- Approximately 100% of the population is within 150 m of a watering point.
- Optimal water quality from Dahla Dam and Zone 1 (backup source).

Long-term outcomes (beyond 2020):

- Approximately 100% of the city (1,200,000 people in year 2030) served about 120 lpcd.
- Approximately 100% of the population is within 150 m of a watering point or has a household connection.
- Optimal water quality from Dahla Dam and Zone 1 (backup source).

*It is assumed that the existing system rehabilitation and expansion, and strategies supply of water using tanker trucks can reach 75% of the population in the near-term.

7.2 Near-term Recommendations

The following sections explain the recommendations of water supply, treatment, storage, and distribution to occur between 2012 and 2015. Appendix C contains the water distribution modeling report and Appendix D contains the water storage descriptions and designs.

7.2.1 Rehabilitate Existing Wells in Zone 4

The recommendation for Zone 4 is to rehabilitate existing wells. Based on the assessment of boring logs and existing information by the USACE PDT recommendations were made on the level of effort that may be required to make the wells at each site operational. Rehabilitation activities consist of verifying existing well and pump performance, reconstructing wells, and replacing old wells with new ones. In some cases a low-end cost and high-end cost estimate were prepared. For additional information refer to Table 23.

7.2.2 Well Field Development in Zone 1

Zone 1 is recommended for development and supply to the city. Water will be extracted, treated, and stored temporarily at the well field site along the Tarnac River before being piped to Kandahar City.

Key Components of Zone 1 Well Field Development include:

- Obtain real estate.

    - The land required for installation of the wells and associated equipment is privately owned and will require permanent acquisition. Coordination with the GIRoA and local officials will be necessary to obtain the land.
- Construct test wells to verify pumping rates.
    - Test wells are needed in the well field area to verify actual pumping rates and substantiate development. The proposed well field will be drilled into the deep aquifer, which is approximately 260 to 335 meters below ground surface.
- Drill/install 26 wells.
    - Assuming that 13,700 m^3 / day flow rate is verified in the field the recommendation is to drill approximately 26 wells to fully and sustainably develop the well field's potential. Assumes each well was operated 50 percent of the time (given down-time, well cycling, power limitations, etc.).
- Install pumps and power source.
    - Currently there are examples of solar powered pumps being used, which should be considered in this case.

7.2.3 Tanker Truck Water Delivery

As the well field is developed trucking water is recommended as a viable option to satisfy immediate need in Kandahar City. Water could also be trucked to various locations throughout the city once the transmission line is constructed. This would minimize the travel distance for trucks and lessen the risk associated with unguarded convoys of trucks hauling water on the highway. The transmission pipeline from Zone 1 will bring the water safely to the city, without destroying roadways, where it can be distributed to people close to their homes.

7.2.4 Raw Water Collection, Treatment, and Storage in Zone 1

Key components of collection, treatment, and storage at Zone 1 include:

- Construct clear well tanks
    - Raw water will be collected at the clear well storage tanks from multiple remote wells at various locations throughout the well field.
    - Consisting of approximately two 7.5 million m^3 tanks covered and reinforced with concrete co-located in well field production Zone 1, these tanks are sized for the short-term by supplying one-day storage at the 20 lpcd demand for the current population of 675,000 people. As part of the main tanks complex, all of the supporting structures and process facilities would be installed with the initial construction. This would include the disinfection system to supply residual chlorination for the piping network. To reduce system start-up costs, a single main tank should be installed. As demand and infrastructure is developed, the second tank would be brought online.

- Construct chlorination disinfection system
    - Inside the chlorine building is a recirculation pump for each of the clear well storage tanks. A chlorine detector, one for each tank and pump is part of the chlorine feed system. The detectors measure the free chlorine residual at the effluent of the tank and if the residual is lower than the set point, the detector signals for additional chlorine. Chlorine feed will be stepped up until the residual value is met; perhaps 4 mg/l as it leaves the source site. The required residual cannot be determined until after the water supply is developed and tested. Conservatively, based on an initial estimated

concentration of 10 mg/l of chlorine in the raw water for disinfection, a total daily demand of 75 kilograms of solid chlorine will be required. The required residual cannot be determined until after the water supply is developed and tested. A typical vacuum feed chlorination connection is provided in Appendix D-1.

- Install generators and booster pumps
  - Clear well storage tanks will be filled and water pumped to the city using booster pumps. After modeling the new distribution and transmission system it was determined that a total of 45 m of head is required to service the new zone hub tanks. Zone 1's well field elevation is located at approximately 1045 m WGS 1984 and Kandahar City's average elevation is 1010 m. With Kandahar located 35 m down gradient from the proposed well field location the well field booster pumps will only need to add 10 meters of running head at 199 l/s. In order to maintain service during maintenance and to reduce the size of the pumps to increase serviceability multiple pumps are recommended. Using three pumps, two for demand and one for backup, the total flow required from each would be 100 l/s. Assuming 50 percent efficiency each pump would be approximately 16kw (21hp). It's important to note that this is running head; start up head may be significantly different and may require a much larger pump depending on the actual alignment taken and if mountains or hills must be traversed.

7.2.5 Transmission Pipeline in Zone 1

From the Zone 1 well field, a bank of booster pumps will send water through a transmission pipeline which will pressurize the distribution system filling the zone hub tanks. As shown in Figure 13 previously, from the well field it runs northwest through private property before reaching a highway that it follows west into Kandahar City. The transmission pipeline is approximately 18-km in length.

- Obtain real estate for alignment.
  - Real estate from the well field to the roadway may be privately owned.
- Construct pipeline.
  - It is recommended that the pipeline be buried and covered to provide some level of protection against illegal taps and other threats.

Figure 14 depicts a flow diagram of the water supply system.

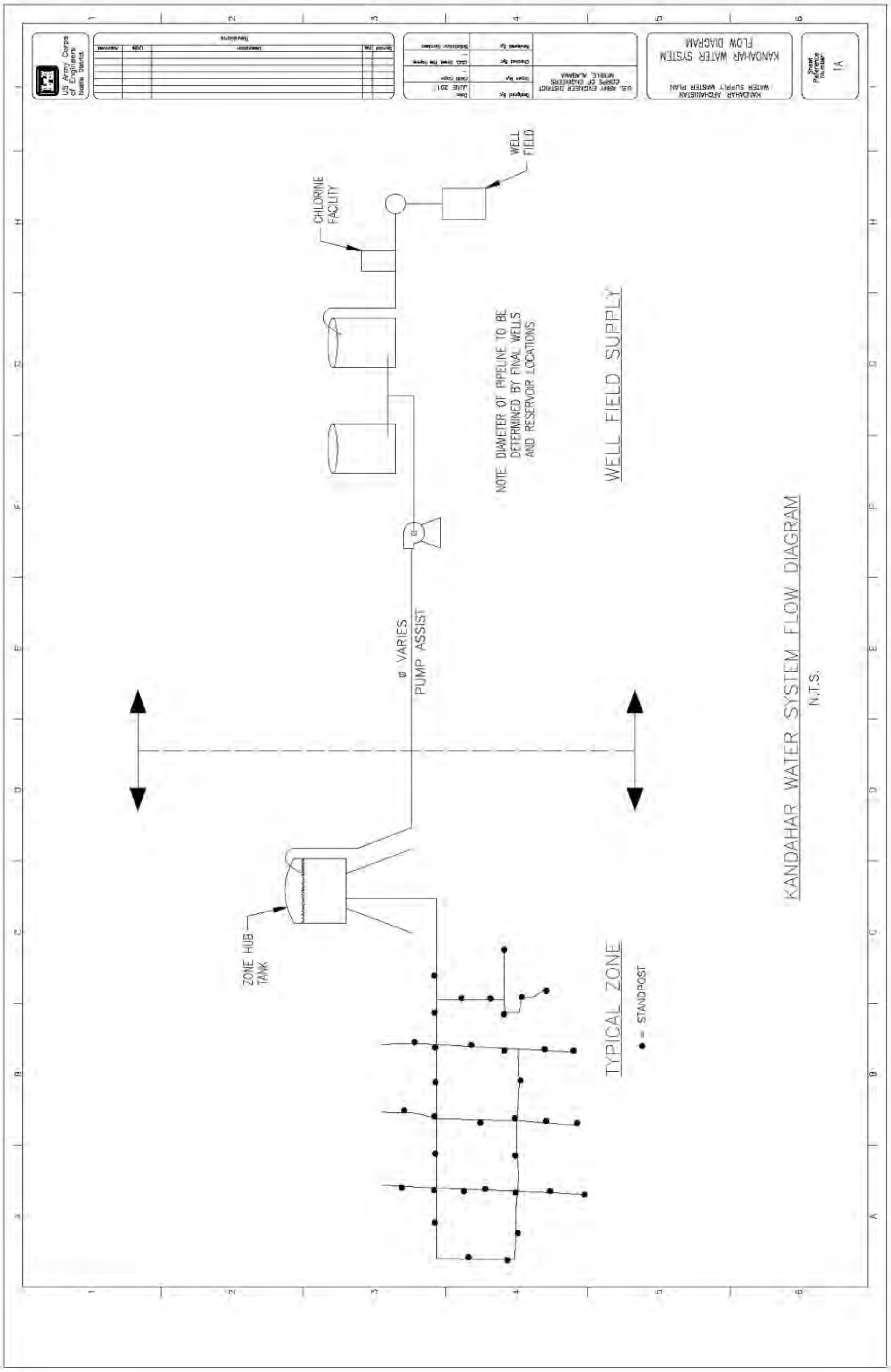


Figure 14. Water System Flow Diagram

7.2.6 Water Distribution System Improvements

Key components of distribution system connection to the Zone 1 supply include:

- Construct distribution system.
  - Phase 1 of the distribution system recommendation is to connect Zone 1 to a new supply system in Kandahar City. The new supply system will connect to 27 zones hub tanks in this phase. The distribution system should initially be constructed to allow for 120 lpcd flowing from Dahla Dam in the latter stages of implementation. Leak detection is not required because all new lines are recommended. The following information reflects that recommendation, however Appendix C also contains pipe sizes that would be required for supplying 20 lpcd from Zone 1 (east end of town) and 20 lpcd from Zone 2 or Dahla Dam (northwest end of town). These scenarios were modeled but are not the recommended plan. Table 33 shows the waterlines and sizes needed for connection from Zone 1 to the hub zone tanks. Figure 15 shows the Phase 1 system coverage and Figure 16 shows the location and spacing of Phase 1, 2, and 3 zone hub tanks (note that the water treatment plant location shown is for treating surface water, not groundwater).

Table 33. Waterlines for Phase 1

Length (m)	Diameter (mm)
261	1,050
736	900
1,122	700
1,935	600
214	550
15,270	500
2,834	450
1,487	400
1,710	350
1,477	300
12,594	250
2,664	200
12	150

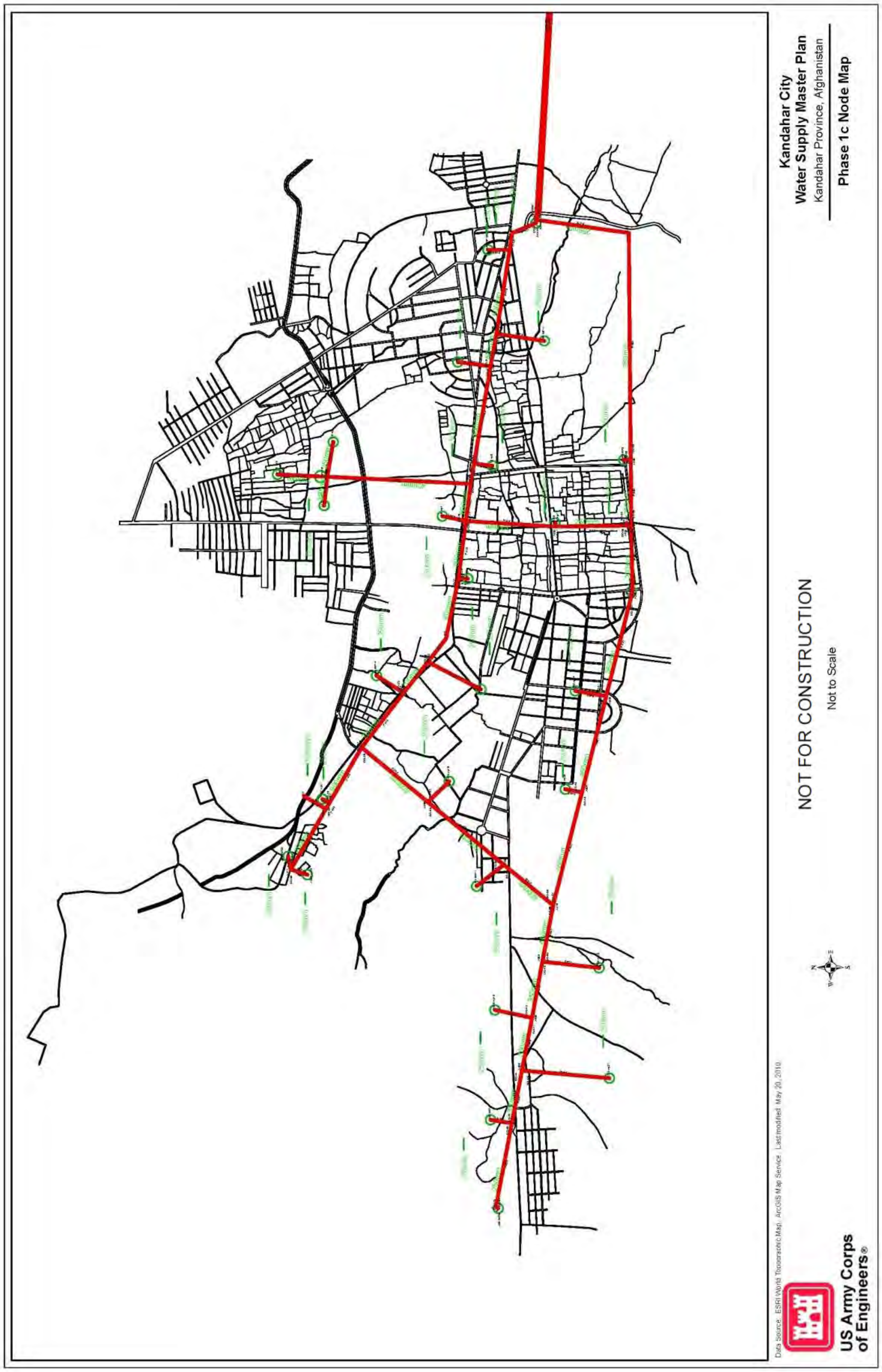


Figure 15. Phase 1 Distribution System Map

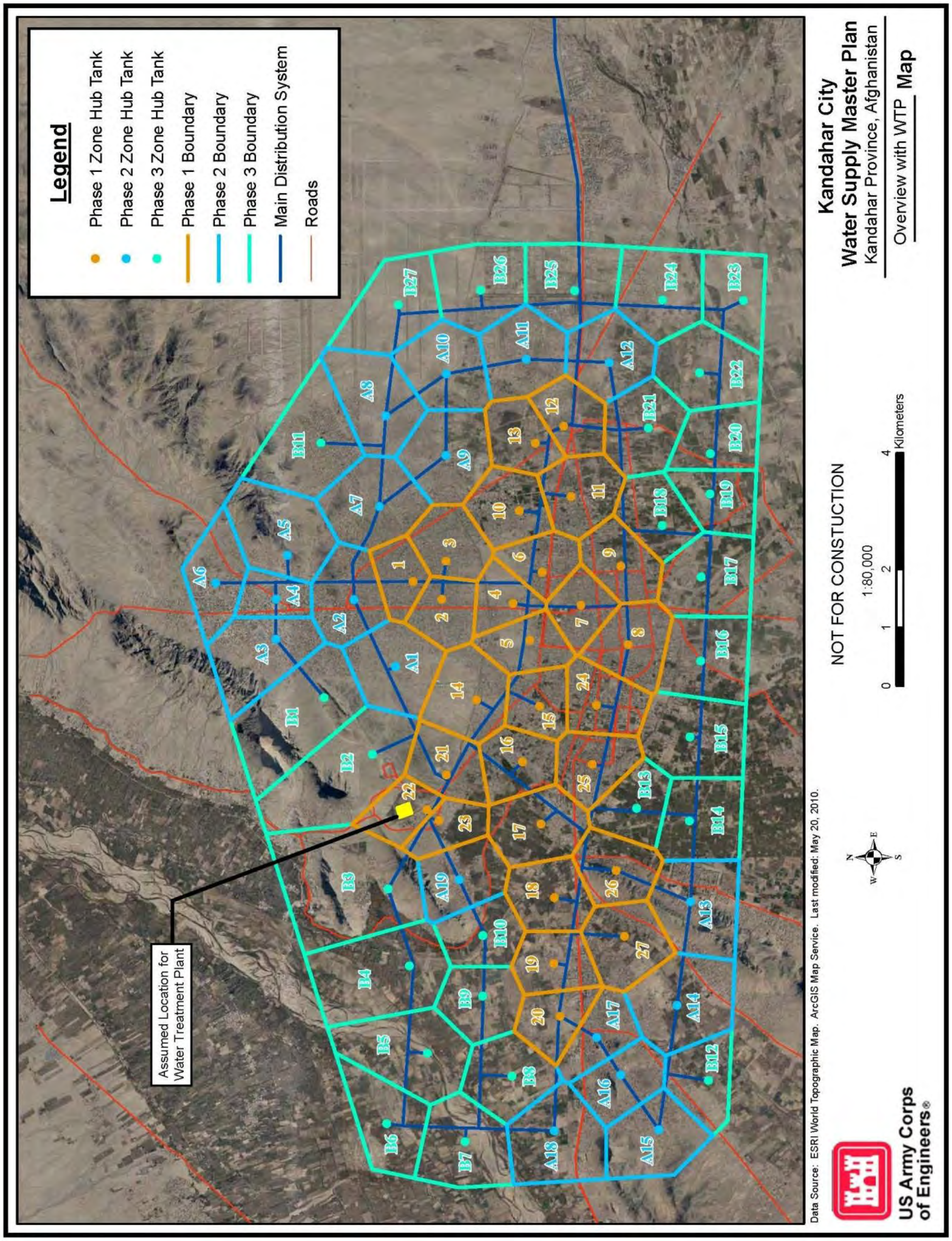


Figure 16. Overview of Hub Zone Locations by Phase

- Construct zone hub tanks.
  - Zone hub tanks are spaced out in the city to provide a minimum 400 m- walking distance to a tank for the entire population. The tanks also provide water storage and pressurize the system. The tank sized for a normal population density of 20,000 people per zone (based solely on population without regard to industry or agriculture) would be (20,000*20 lpcd)*1.2 = 480,000 L use for a standard size of 500,000 liters. The tank size for a high population density of 57,000 people per zone, based solely on population without regard to industry or agriculture, would be (57,000*20 lpcd)*1.2 = 1,368,000 L. Rather than using a single 1,368,000 liter-tank to service the high population density areas, it is recommended that multiple standard size tanks of 500,000 L be used. This would increase constructability, and there would presumably be a cost savings from economy of scale. This would require redundant tanks but would increase reliability in the high density areas. For instance, if one tank within a high density zone were off-line, the entire zone would not be without water as supply would be provided by the redundant tanks. A preliminary structural plan and drawing for the zone hub tank is available in Appendix D-1.

- Construct watering standposts and network.

  The number of standposts for each zone is calculated using two criteria. The first is based on its population density. Using 10 hours of usable time per day and a 5-minute collection time, a zone with a normal population density of 20,000 people would be: 600 min / 5 min = 120 collections per standpost per day; 20,000 / 120 = 167 faucets required for each person to be supplied with their daily 20 lpcd. A zone with a high population density of 57,000 people would require 57,000 / 120 = 475 faucets. The second is the stipulation received as part of the statement of work that travel distance be limited to 150 meters. Based on the area of each zone, there should be a minimum of 60 standposts per zone. In order to meet both criteria, three faucets will be supplied per standpost. This gives 167 faucets / 3 faucets per post yielding approximately 60 standposts per normal density zone. Preliminary plans and drawings of low density and high density standposts are located in Appendix D-1. A schematic showing how public standposts connect to zone hub tanks is shown in Figure 17.

  To satisfy the immediate needs, a variation of the public standpost has been included with this Master Plan. This variation allows for a temporary on-site storage tank to be installed and serviced by water trucks. As construction progresses, the on-site tank would be removed, and the standpost would be directly connected to the distribution system. Once the distribution system is connected to the supply, the public standposts can be connected to the zone hub tanks. Locations of 20 public standposts have been identified by local stakeholders for immediate construction. These are shown in Figure 18.

  If existing waterlines are functioning or can be repaired they are recommended for connection between the zone hub tanks and watering standpost. The leaks detection should be performed using the existing well water and acoustical sounding equipment. The section of waterlines that are shown to need isolation valves in the criticality analysis should have the isolation valves installed during the repair of leaking waterlines. Information and a scope of work for use in sounding technique contacts are available in Appendix D.

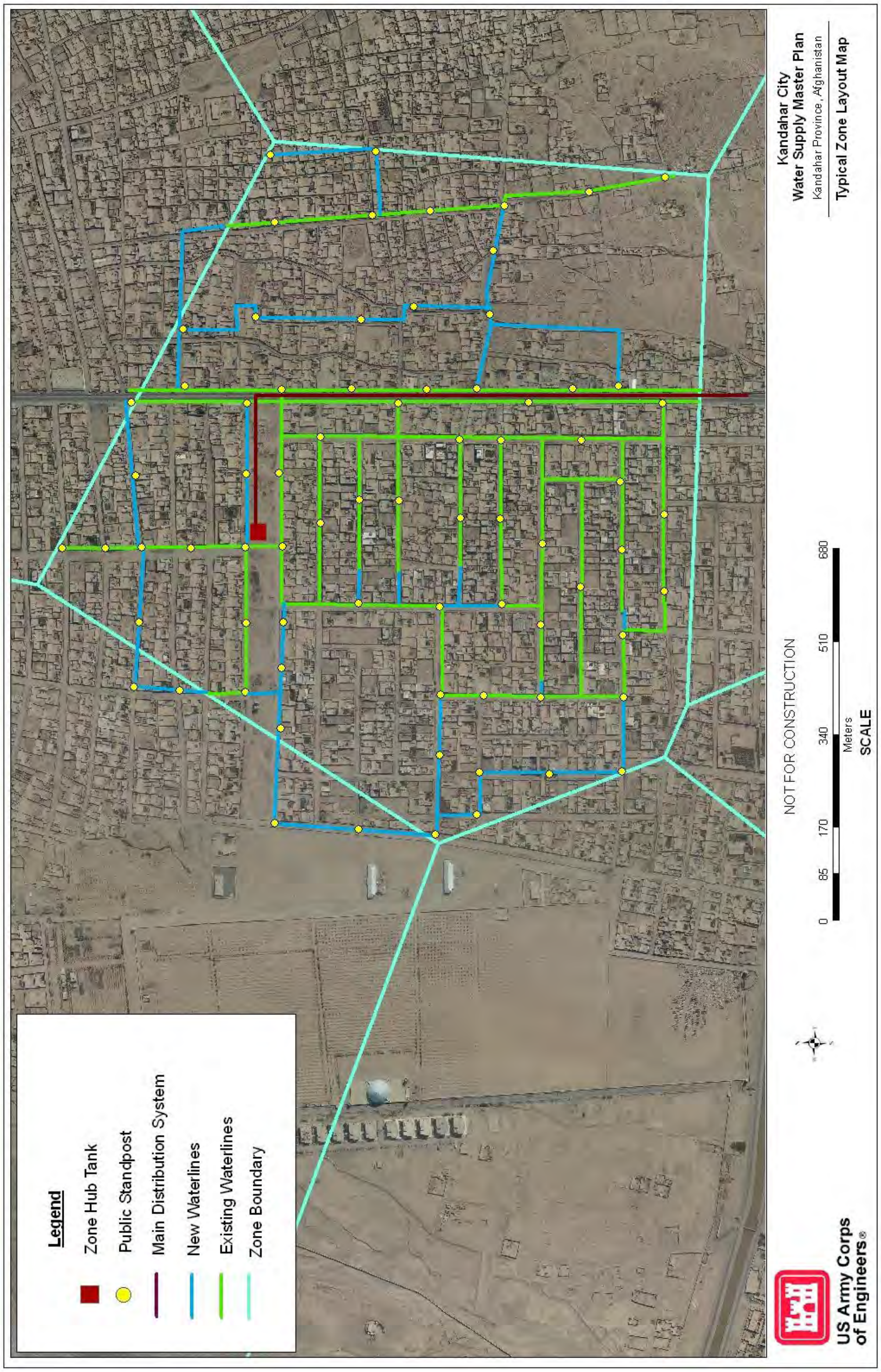


Figure 17. Typical Hub Zone Layout

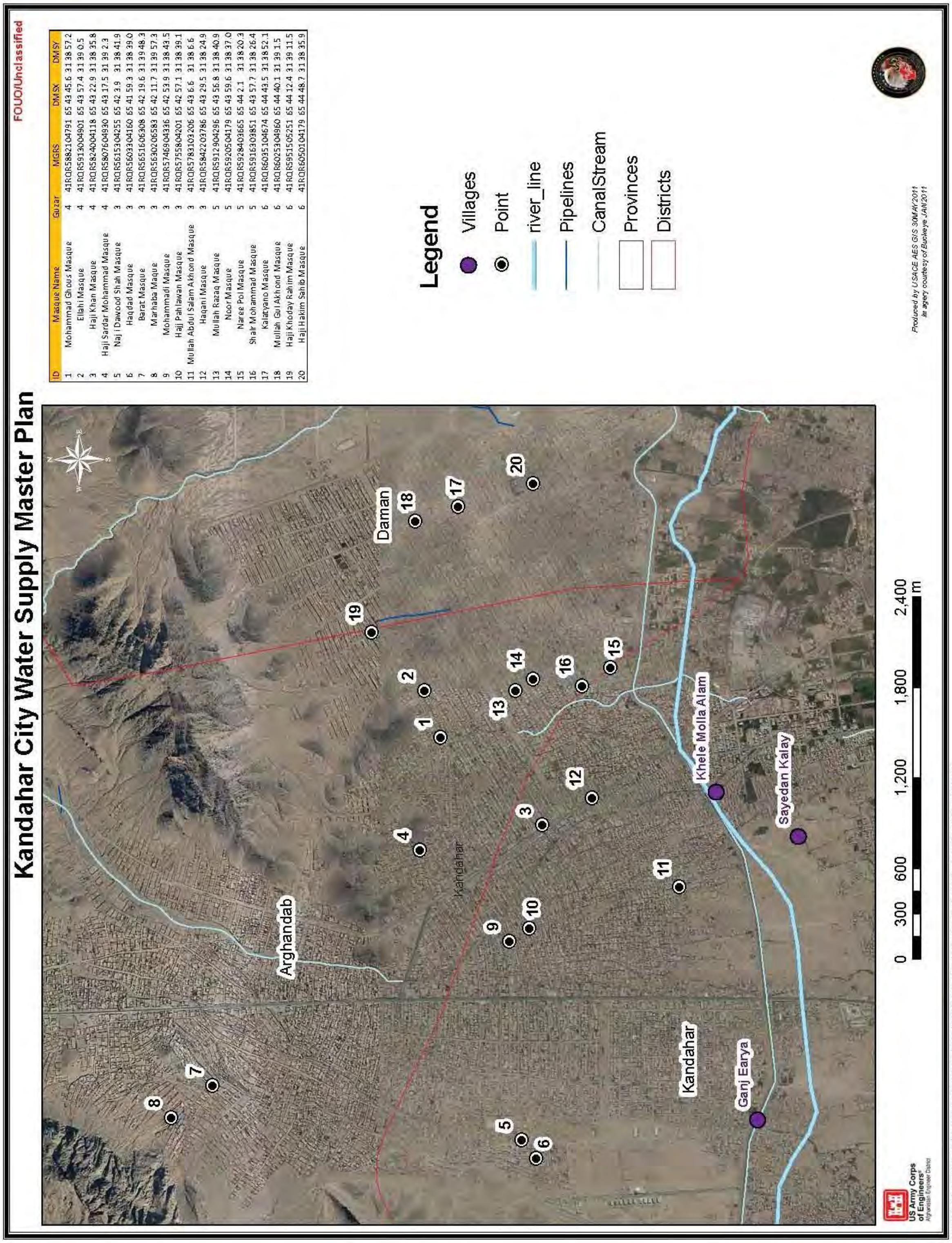


Figure 18. Public Standpost Locations

7.3 Mid-term Recommendations (2016-2020)

7.3.1 Dahla Dam Supply Line

The transmission line from Dahla Dam reservoir to the city requires additional planning, but in general the pipeline will be approximately 34 km and it will connect to the distribution system in Kandahar City at the northwest end of town.

Key components of the supply line:

- Obtain real estate for alignment.
    - Real estate from the reservoir to the roadway is privately owned.
- Construct pipeline.
    - It is recommended that the pipeline be buried and covered with concrete to provide some level of protection against illegal taps and other threats.

7.3.2 Treatment Plant

The treatment plant should be built in phases to accommodate population growth through the year 2030. The first increment will provide 50 percent of total capacity (4,000 m^3 / hour), second will provide 75 percent, and third will provide 100 percent (8,000 m^3 / hour). A study to determine actual treatment requirement of surface water from the dam will provide more detailed information on treatment required.

7.3.3 Water Distribution System Improvements

Key components of distribution system connection to the Zone 1 supply include:

- Construct distribution system.
    - Phase 2 of the distribution system recommendation is expanding the network by adding an additional 19 zone hub tanks. The distribution system should be constructed to allow for 120 lpcd flowing from Dahla Dam. Table 34 shows the waterlines and sizes needed for connection from Zone 1 to the zone hub tanks. Figure 19 depicts the distribution system recommended for construction in Phase 2.

Table 34. Waterlines for Phase 2

Length (m)	Diameter (mm)	Length (m)	Diameter (mm)
340	1,050	7,472	400
657	900	4,779	350
3,095	700	13,008	300
1,352	600	1,181	200
4,754	550	2,073	150
8,809	500	784	100
213	450		

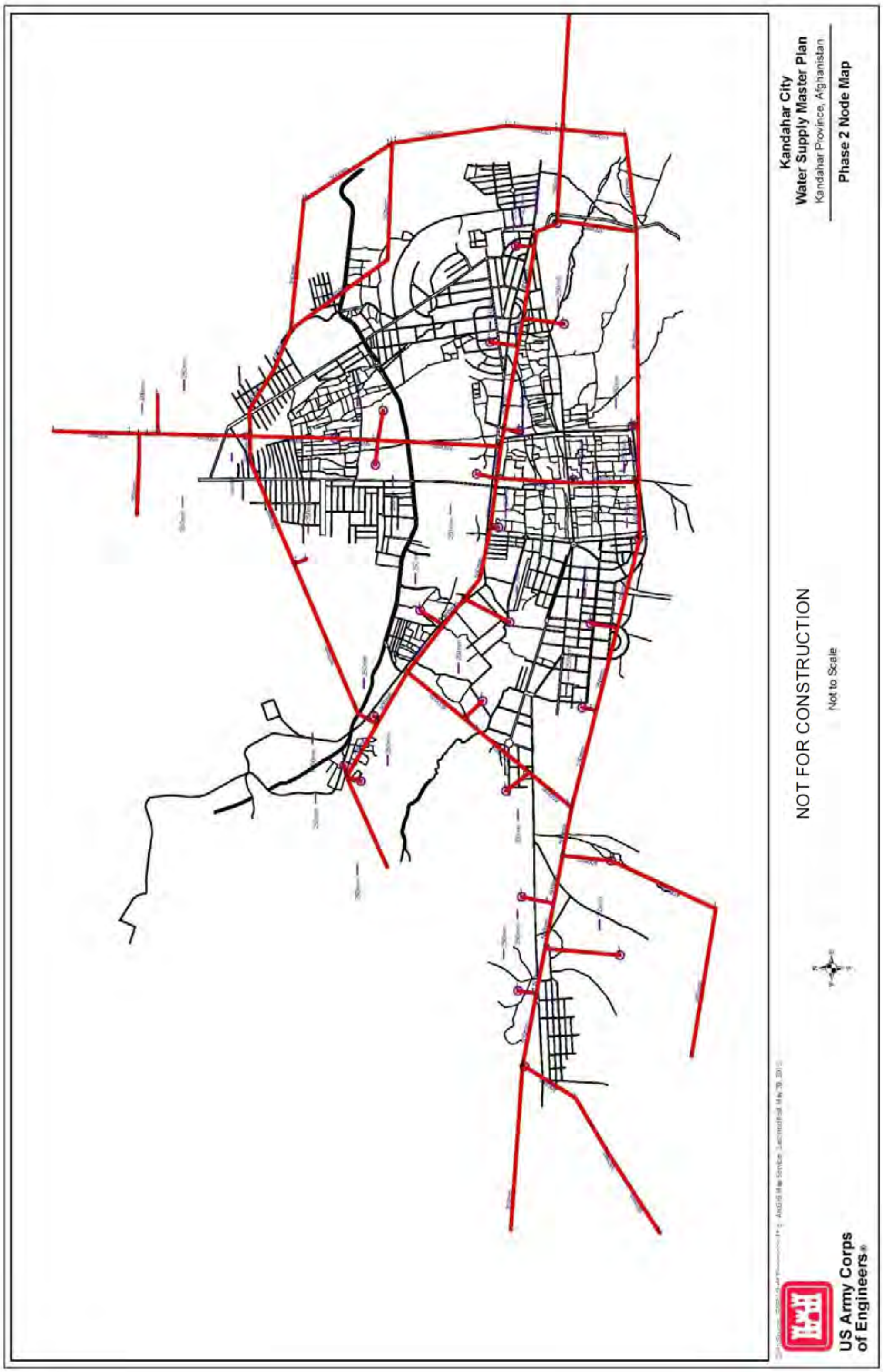


Figure 19. Phase 2 Distribution Network Map

- Construct zone hub tanks.
    - This phase calls for construction of 19 additional zone hub tanks providing all residential areas with access to zone hub tanks and public standposts. A preliminary structural plan and drawing for the zone hub tank is available in Appendix D-1.

- Construct watering standposts and network.
    - This phase calls for roughly 500 normal density standposts. Actual numbers may vary during implementation based on more detailed population counts. Plans and drawings for standposts can be found in Appendix D-1.
    - Existing water lines may be used but leak detection is recommended. The leak detection should be performed using the existing well water and acoustical sounding equipment. The section of waterlines that are shown to need isolation valves in the criticality analysis should have the isolation valves installed during the repair of leaking waterlines. Information and a scope of work for use in sounding technique contacts are available in Appendix D.

7.4 Long-term Recommendations

The system was modeled to show additional future expansion scenarios to new growth areas with supply from Dahla Dam and the Ant Valley. These upgrades are shown in Appendix C.

Key components of distribution system connection to the Zone 1 supply include:

- Construct distribution system.
    - Phase 2 of the distribution system recommendation is expanding the network by adding an additional 19 zone hub tanks. The distribution system should be constructed to allow for 120 lpcd flowing from Dahla Dam. Table 35 shows the waterlines and sizes needed for connection from Zone 1 to the zone hub tanks. Figure 20 depicts the distribution system recommended for construction in Phase 2.

Table 35. Waterlines for Phase 3

Length (m)	Diameter (mm)	Length (m)	Diameter (mm)
998	1,200	9,836	500
1,973	1,050	7,245	450
1,352	900	22,841	400
1,427	800	2,086	350
949	750	17,355	300
596	700	8,476	250
889	650	8,745	200
3,340	600		

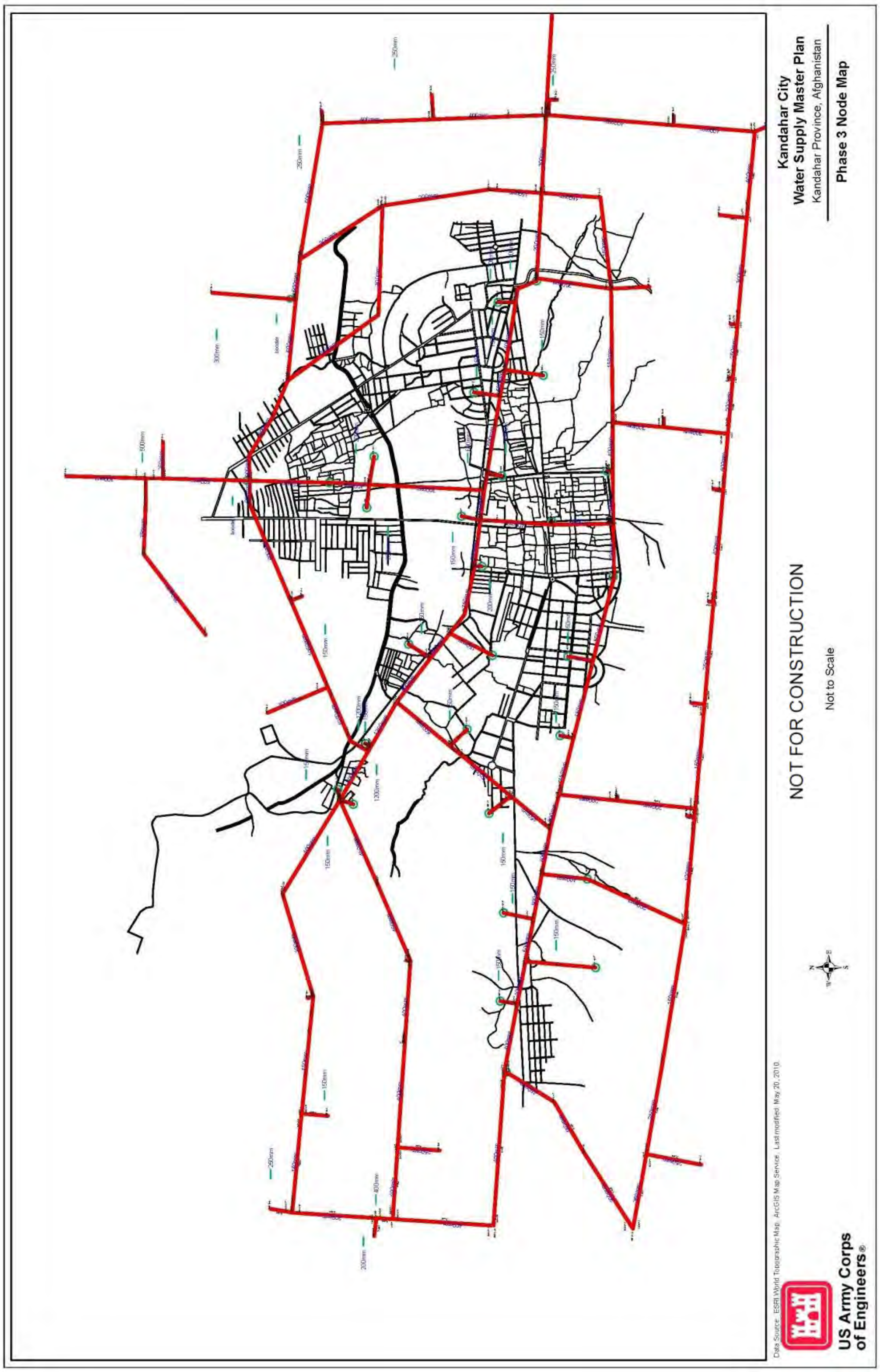


Figure 20. Phase 3 Distribution Network Map

- Construct zone hub tanks.
    - This phase calls for construction of 27 additional zone hub tanks providing all residential areas with access to zone hub tanks and public standposts. A preliminary structural plan and drawing for the zone hub tank is available in Appendix D-1.

- Construct watering standposts and network.
    - This phase calls for roughly 1,620 normal density standposts. Actual numbers may vary during implementation based on more detailed population counts. Plans and drawings for standposts can be found in Appendix D-1.

7.5 Recommended Construction Phasing

Table 36 shows an overall approach to construction phasing. In the near-term, the focus is on rehabilitating the existing system and providing treated groundwater to the community. This is accomplished by constructing public standposts and hauling water with trucks back and forth from the Zone 1 and Zone 2 well fields. The existing municipal system is also rehabilitated to provide treated water for the population. In addition to this work, the existing distribution system is upgraded in preparation for connection to the Dahla Dam supply. Once raw water supply from Dahla Dam is connected, the remaining zone hub tanks and standposts are to be constructed in the existing residential areas not yet served, and connection to the distribution system is recommended.

Table 36. Project Construction Phasing

Groundwater Supply Scheme	2012 - 2015	2016 - 2020	Beyond 2020
Drill test wells at Zones 1			
Fix pumps and generators, and add treatment to Zone 4			
Construct well field and add treatment in Zone 1			
Truck water from Zone 1 to stand posts			
Deactivate Zone 4 well field			
Surface Water Supply Scheme			
Construction at Dahla Dam			
Construct transmission pipeline and connect to distribution system			
Construct first increment of treatment (50%)			
Water supply from Dahla Dam reaches the city			
Construct second increment of treatment (75%)			
Construct third increment of treatment (100%)			
Distribution Network Scheme			
Perform leak test and repairs			
Construct public stand posts in critical areas, for tanker truck service			
Utilize tanker trucks to haul water from well fields to public standposts			
Upgrade distribution network to provide 20 lpcd, then 120 lpcd			
Construct zone hub tanks for existing system			
Expand distribution system to unserved residential			
Construct zone hub tanks in unserved residential			
Construct public stand posts in remaining unserved residential			
Expand distribution network, zone hub tanks, and stand posts to new growth areas			

One approach to construction phasing associated with the distribution network and supply from Zone 1 is shown in Figure 21. This phasing figure assumes that the storage tanks in the Ant Valley are constructed and an initial new source of water is connected to the distribution system from the northern portion of the city, through District 9. As Zone 3 (Ant Valley) was not identified as a sustainable aquifer in the near-term or long-term, this phasing approach may not be suitable. If main storage tanks are located in the eastern portion of the city or a connection to the transmission pipe from Zone 1 occurs here, the construction phasing is likely to change in the final Master Plan. Input on socially and locally preferred construction phasing is encouraged.

The benefit of this approach is that the distribution system can be incrementally upgraded to provide water as pipes in each phase are upgraded. It is expected that the leak identification, repairs, and installation of new pipes will be a difficult and lengthy process. By focusing on smaller portions of the city, water can be supplied in phases to more quickly supply the available water.

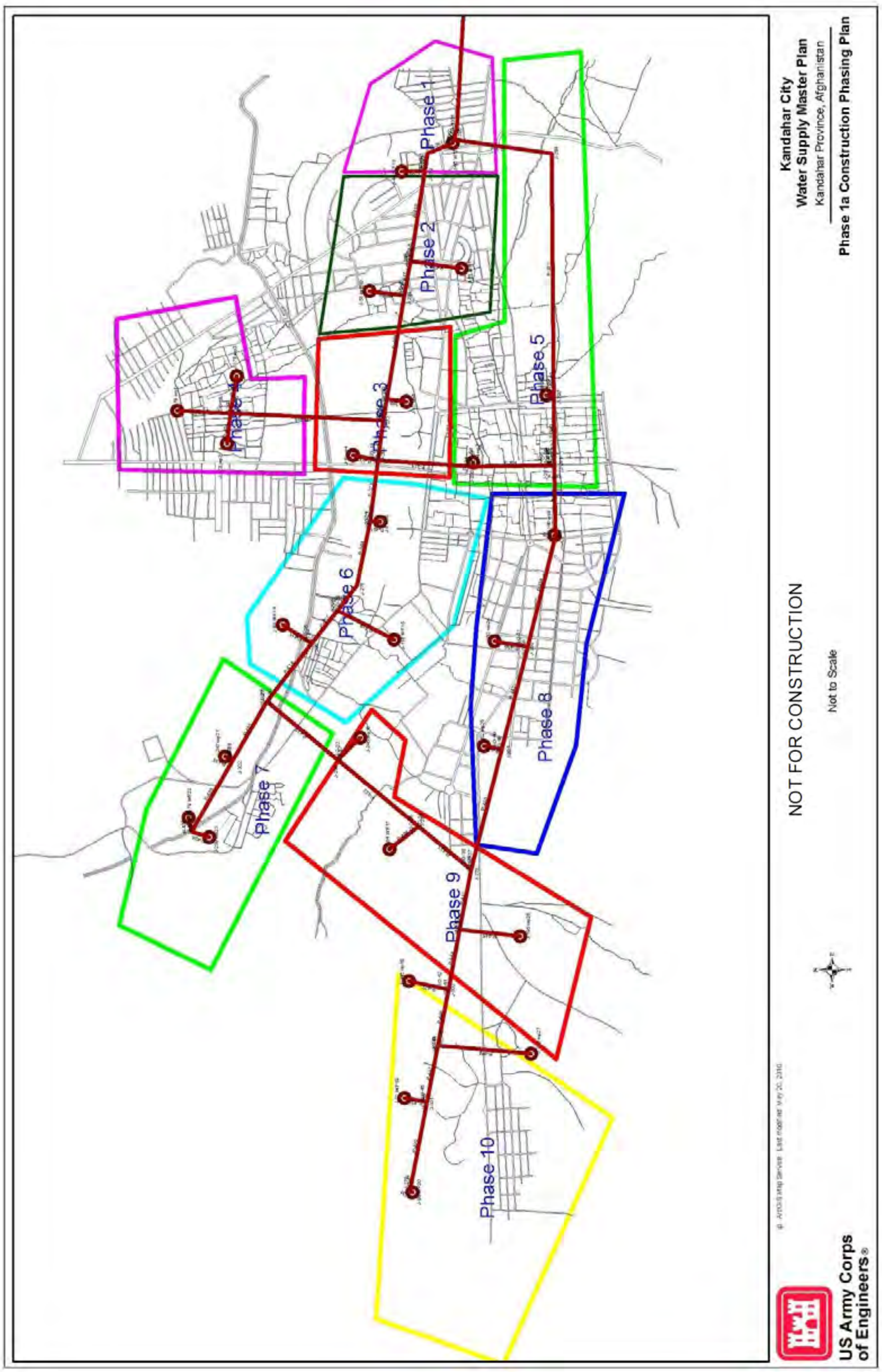


Figure 21. Construction Sequencing Plan for Phase 1

7.6 Economical Sustainability

In arid lands, the availability of water is either inadequate or restricted due to difficulties such as power outages. In order for any community water system to support its customers, it must provide services and a product that is both affordable and reliable. The planned approach within this system is tempered to meet the burgeoning expansion of a water system that must develop its support structure while growing its revenue source. This is a modified approach from the design of more western systems. This Master Plan concept is based on the fundamental premise that as this system develops there will be a scarcity of water quantity. Excessive customer demand will require the utility to place controls on how much and how often the water is delivered. The problem with urban water scarcity, in the formative development, unless the system is designed such that poorer people can be connected at affordable rates, the system will no longer be supported and it will fall into rapid disrepair.

The conveyance of water from the source to the customer is typically substantial cost of system construction and if the design is based on a continuous supply of water, then the diameters of pipe would necessarily be of greater diameters. Construction of the system is made more affordable by the development of service zones. The service zone receives its water from the main supply source, which can also be supplemented by individual wells within the individual zone. The "Hub" tank acts as the single source provider to its respective zone, such as a hub with radial spokes, hence the name.

Systems that are designed for continuous supply will fail when adequate water quantities are no longer available. In a system designed for continuous supply, intermittent water supply can cause a myriad of problems, some of which are:

- An overall shortage of water
- Insufficient pressure in the distribution system (sometimes can be zero)
- Inequitable distribution of the available water
- Very short duration of supply

One of the most serious problems that can be generated from an oversized system with inadequate water supply is high levels of contamination. The zone hub approach is determined to be the best plausible approach to aid the utility company in control of the water supply and balanced delivery. In this zoned-approach as laid out, the balance of pressure is more evenly defined in that the source of pressure is the zone hub tank. This tank serves a smaller district network than the size that a continuously supplied system normally accommodates. More equitable distribution of pressure can be controlled because the zones are smaller. It may not be possible to achieve minimum costs of construction at the beginning in that the system is sized to meet its future needs.

Initially, supply of clean water will be to the standpost for all customers. They will have to provide their own cans and transportation, but this is not unusual. The utility will have to determine how to charge people for this water at the standpost or the utility will have to absorb the cost initially while the system is under development, design, and construction. Poorer people tend to use more water in an effort to improve conditions for themselves. Because the water must be carried, perhaps that will help authorities dissuade some forms of excess consumption. However, spillage and theft can still be a problem.

Over time, as the water system utility and network develop a greater number of people are expected to become more financially affluent. More affluent people can then have their houses served with a meter and the water can be charged specifically for the individual residence or business. Rates can be determined for —metered” customers versus those who still must collect and transport their water over ground, i.e. —unmetered.”

Water system needs for Kandahar City are not expected to be fixture demand driven, i.e. pressure/quantity per fixture unit in a household or business. Here, demand driven means the instantaneous water pressure and quantity demand that occurs on a plumbing system when fixtures are operated simultaneously within a building. This demand creates a drawdown of pressure on the distribution network that requires sufficient pipe size not to reduce the working pressure too much so that the residual pressure does not go below an established minimum. These minimum pressures are set by various utility companies in response to insurance companies, fire departments, and certain equipment operations in commercial and industrial areas.

The vision set forth in this Master Plan is for areas where water scarcity is critical. The individual will do more to protect and preserve his own water supply than when served by a public supply source. As families and individuals become more affluent and can afford to be individually-metered, the goal would be for that individual to establish his own housetop tank. Each house or business will support its own plumbing system by the roof top tank (Figure 22). Demand on the public network and zone hub tanks will be to strictly fill the roof top tanks, which should not be —instantaneously” required. Rather, roof top tanks can fill over several minutes up to hours depending on the size of the zone. The implementation of zone hub tanks allows the instantaneous demand on the network system to be significantly reduced. The hub tanks provide the water source to the individuals within the zone of its influence—piping sized by the design engineer. With a reduced demand and a smaller piping diameter requirement, the system becomes more constructible and the water more affordable to all potential customers.

Initially, when the system is first proposed and constructed, it is expected that a large percentage of the customers will be relatively poor; a smaller percentage being of moderate financial means; and finally a very small percentage being appreciably wealthy. At the same time, most likely an eschewed demand will exist on the system because of initial overcrowding at the standpost for water and then as the reliability of the system may be intermittent.

Eventually, as stated above, the more affluent customers become, the more likely they are to want their own buildings with individual meters. The plan would be that those buildings, shops, and hotels should furnish their own peak water demand tanks on their own roof tops or nearby elevated storage. Figure 22 shows the use of roof top tanks. Note that this figure is an example and not located in Kandahar City. These tanks serve the building on which they are placed and connect to the plumbing. Water meters can be installed at street level on the fill line of each tank.

Figure 22. Roof top Tank Photo

8.0 ENVIRONMENTAL, SOCIAL, AND POLITICAL EFFECTS

8.1 Environmental Effects

8.1.1 Wastewater

There is currently an effort building to study and address wastewater in Kandahar City. That study should utilize recommendations from this Master Plan during planning and design of a system. Similarly, this Master Plan should adapt to recommendations from that report if it makes sense from a social, environmental, or engineering standpoint.

There is not a sanitary sewage collection system in Kandahar City. Residential waste is discharged to compost toilets or cesspools. There are four public latrines in Kandahar City which are in poor condition. The sanitary waste collection system should initially be situated in centralized locations similar to the zone hub water distribution points. Latrines should be located within a safe distance from the water zone hub standposts. Latrine areas should also include exterior facilities to wash clothing. Creating the sanitary collection areas would increase the water usage above the 20 lpcd for zone hub stand usage. The wastewater treatment facilities should be located to the south of the city to utilize gravity flow.

There are various treatment options but a very effective alternative is a lagoon system. In a lagoon system, the treatment of sewage is accomplished with bacterium that breaks down the organic wastes. Lagoons do require periodic maintenance to control the water weed and vegetative growth adjacent to the lagoon. These other treatment processes (e.g. activated sludge, biological reactor, etc.) have increased maintenance, energy consumption, and complexity as compared to oxidation lagoon systems.

8.1.2 Resource Sustainability, Effects of Groundwater Development

Based on the modeling conducted for this Master Plan the recommendation is to provide sustainable maximum production rates of 13,700 m^3 / day at Zone 1 and 10,000 m^3 / day at Zone 4. The cumulative effects of these production rates do not reduce city aquifer levels in Kandahar City by substantially more than one meter beyond the drawdown resulting from current operations. If Zone 2 is developed in addition to Zones 1 and 4 the cumulative effects on drawdown in Kandahar City also need to be determined.

Continued use of household wells and full development of the city's municipal well system could result in increases in aquifer drawdown or production rates exceeding 10,000 m^3 / day in Zone 4. Regulation of household wells could be needed once production from well fields begin or later when full production is realized. Given the current situation regulations could be difficult to enforce, especially in areas without piped water such as District 9.

Ultimately, if long-term supply from Dahla Dam is achieved then the effects of drawdown in the city would be temporary if production of groundwater ceases. Once the municipal wells in Zone 4 are deactivated the system would begin to recharge itself. Wastewater reinfiltration could also minimize these impacts as discussed below.

Another potential environmental effect related to trucking of groundwater from well fields into the city is the degradation of roadways. If trucks are used on a large scale to make multiple trips on a daily basis, there could be adverse impacts to roads. Heavy trucks full of water could possibly tear up roads and cause problems for the public. There may also be security issues to assess with along the route from Zone 1 to the city. These impacts need further analysis and the costs of road repairs should be considered and weighed against the cost of a transmission line.

8.1.3 Wastewater Reinfiltration

Increases in water supply capacity to Kandahar City will result in increased discharge of wastewater to the ground surface. A portion of this wastewater will enter the groundwater system through the unconfined aquifer. Several simulations were made to evaluate potential impacts of this reinfiltration. Reinfiltration simulations were performed to reflect recharge to the ground surface at 50 and 100 percent of the 20 liters per capita per day for 500,000 people (5,000 and 10,000 m^3 / day, respectively). The area of the greatest increase in head occurs east of the city and north of the Loy Walla Canal. The increases in head in this area are nearly twice the average water level increase across Kandahar City. This is due primarily to variable thickness of the aquifers across Kandahar City. Immediately to the north of this area of maximum water level rise, there are apparent rock outcrops to the ground surface. The presence of this rock outcrop south of the main mountain range indicates that the bedrock units are closer to the surface in this area resulting in thinner aquifers when compared to the aquifer thickness in Kandahar City. Consequently, this area may have less capacity to infiltrate water.

The water level rise in the more populated portion of Kandahar City ranges between 2 and 6 meters resulting from the average infiltration of 10,000 m^3 / day. The capacity of the unconfined aquifer to accept this recharge is promising for future development. Increases in the quantity of water supplied to the city will ultimately lead to more water being discharged. This may be passive (e.g. uncontrolled discharge to the surface as currently occurs) or a more active management strategy may be employed, which could include treatment and strategically located infiltration galleries.

Regardless of the methodology employed, a portion of the wastewater generated will propagate down to the underlying aquifers over time. This reinfiltration of wastewater will help mitigate cones of depression that currently exist in Kandahar City. However, the quality of the water infiltrated must be evaluated. If poor quality water is directly discharged to the aquifer system, the risk of water quality degradation in the confined aquifer currently used for water supply will increase due to the downward gradient in this area. Additional study efforts are needed to determine travel times for this available recharge to reach various aquifer units in Kandahar City. Given this potential to recharge the aquifers in Kandahar City through reinfiltration, further evaluation of this condition is warranted. Potential negative impacts of wastewater discharge may be mitigated and turned into positive impacts if additional infrastructure were constructed to treat the increased wastewater supply and strategically recharge the deeper aquifers via well galleries.

8.2 Social Effects / Project Beneficiaries

The most significant social effect resulting from improved access to potable water is improved health. The area has a history of illness and recent diarrhea outbreaks have been observed. The main reasons behind disease outbreaks are lack of access to potable water, feeding children with polluted utensils and eating fresh inadequately washed vegetables etc. Disease outbreaks mostly affect children.

Studies have shown that poor countries with improved water and sanitation had annual population growth rates of around 4% (some higher), whereas poor countries without such services had a 0.1% growth rate, if any at all. An improved water infrastructure relaxes demands for time and labor for sustenance needs, freeing social capital for human resource development, meaning time and money used in the care of children affects productivity, opportunity, and entrepreneurship. Poverty reduction and health are both proxies for economic development, with improving health and decreasing poverty typically correlated.

The sizes of Kandahar City's industries are not well articulated so inferences on employment, water use, and future potential are not possible. Providing potable water will provide immediate health benefits, but certainly in the long-term as the situation stabilizes there will be noticeable benefits for commercial and industrial sectors as well.

The recommended plan will improve the agricultural sector's efficiency and opportunity. As previously discussed, the recommendation at Dahla Dam is to raise the dam and increase storage capacity. Based on preliminary analysis by USACE the additional storage provided by a five-meter raise would meet long-term demand of Kandahar City and increase the amount of water available for irrigation. Dam raises greater than five meters would provide even more irrigation for the region, increasing economic opportunities and improving both rural and urban quality of life.

Irrigators will also benefit from the proposed project because of increased operational efficiency and management of diversion canals. In order to effectively supply water to Kandahar City on a continuous basis a water management plan should be developed to regulate discharges from the reservoir. Local authorities must integrate management of irrigation and municipal water supplies to ensure that allocations are made that meet the demand of both of the dam's project purposes. One benefit of integrated management will be better timing of and more predictable releases of irrigation water for users of the canal system.

Other potential impacts on the agricultural sector from supplying municipal water to Kandahar City need to be determined. With economic development spurred by water infrastructure, a by-product could potentially be the processing, packaging, and exporting local agricultural products that are brought in from local villages. On the more nefarious side, there is the potential for illegal taps, or fetch and ferry services, that will draw water for agriculture.

There are two big agricultural research farms in Kandahar City that could benefit immediately from access to water. One is located near the Zone 1 aquifer and would be an ideal candidate for water from the well field once Dahla Dam is connected to the city.

Assuming groundwater development occurs at varying degrees within Zones 1 and 2, there is a significant possibility that as the transition is made to supply the city from Dahla Dam long-term, the well fields could produce localized benefits for communities nearby. For example, farming and rural populations along the Arghandab River could benefit from a relatively clean or even treated source of water from the river. Similarly, the water from Zone 1 would presumably have capability to be treated at the wellhead, which could allow for that source of water to supply nearby rural communities or small villages. The overall economic and health impacts are difficult to quantify, but in general there would be an improvement in quality of life in these communities similar to improvements within Kandahar City.

8.2.1 Stakeholder Input, Public Involvement

An over-arching principle of the Master Plan is collaboration and integration with AUWSS, local government, stakeholders, independent government organizations, and NGOs. Many components of this document are derived from prior work efforts by these groups and input received thus far. Additional input from stakeholders was received during a comment period on the draft Master Plan and incorporated accordingly.

8.2.2 Transboundary Issues

The Helmand River Basin lies mostly within southern and central Afghanistan but flows into Iran when it reaches the Sistan Basin. The Helmand River is important to southern Afghanistan as a source of drinking water and irrigation for people living along the river and its tributaries. Along Afghanistan‘s western border, the river crosses into Iran where it also has environmental and economic significance. As a transboundary river, water resource decisions that affect flows of the Helmand can be politically sensitive.

Within the Helmand River Basin are the Arghandab, Tarnac, and Arghistan Rivers, which are all situated in the mountainous region of northern Kandahar Province. After these rivers flow south and converge at the Arghandab River, the Arghandab River flows west out of Kandahar Province for approximately 100 kilometers before emptying into the Helmand River. The Helmand River meanders southwest across southern Afghanistan several hundred more kilometers before reaching the Sistan Basin and crossing into Iran. The Sistan Basin is ecologically significant because of the important wetland and aquatic resource habitat it provides the region, such as habitat for large populations of migratory birds.

The purpose of this section is to state the potential impacts recommendations made in this Master Plan could have on flows in nearby rivers. These potential impacts should be considered during the decision-making process. Impacts to the Helmand River flows can be derived based on the analysis and conclusions in this Master Plan. Some of those impacts are temporary in nature and others are not. Based on all available information and the identified sustainable yield of 13,700 m^3 / day produced from the Zone 1 aquifer, the modeling results show the potential flow reductions to be:

- Arghandab River flow volume is reduced by approximately 1%.
- Tarnac River flow volume is reduced by approximately 5%.
- Arghistan River flow volume is reduced by approximately 2%.

Based on all available information and the identified sustainable yield of 9,000 m^3 / day produced from the Zone 2 aquifer, the modeling results show the potential flow reductions to be:

- Arghandab River flow volume is reduced by approximately 4% total (locally may be higher).
- Tarnac River flow volume is reduced by approximately less than 1%.
- Arghistan River flow volume is reduced by approximately less than 1%.

Of these three rivers, the Tarnac River and the Arghistan River are smaller systems, and given the location of the Zone 1 aquifer in relation to the Tarnac River, some flow reduction is to be expected. The flow reductions identified are shown to be extremely minimal to none and downstream impacts are not concerning. The Arghandab River is the largest river of the three, and given that the impacts are extremely low to none, the downstream impacts are not concerning.

9.0 REAL ESTATE ACQUISITION

Implementing this Master Plan will require consideration of real estate needs. Local government officials should be engaged in the real estate needs early in the implementation phase of this plan. It is understood that real estate needs can create challenges and may even result in changes to the proposed network. In order to minimize impacts to private landowners, the design of the distribution system follows roadways, which are owned by the municipal government. The layout of the distribution network proposed in this plan is flexible as well and can be adapted to accommodate available real estate. However significant changes in alignment may impact the hydraulic functions of the system and require remodeling efforts.

It is critical to engage local officials and community leaders early to begin addressing land needs. Shuras are the commonly used method of engagement in the community. Community meetings or shuras are vitally important in Afghanistan. Educating leaders on the process and showing benefits to the project are good ways to encourage participation. Community leaders should be included early in the project planning phases, especially in relation to constructing distribution piping. Lands will be needed in perpetuity to support the distribution system and operations and maintenance.

10.0 INVESTMENT PLAN

Table 37 depicts the investment plan which focuses on the near-term solutions. The investments shown correspond to the recommend plan and descriptions presented throughout the document. Only investments in the near-term are detailed due to the immediate need of existing residents in Kandahar City. As the city grows and clean water is supplied the expansion of the water distribution system will be determined by the growth patterns of the city in the mid- and long-range. It is recommended that as the city grows the Master Plan be updated to reflect the needs of the city.

Table 37. Investment Plan

Project	Suggested Investment Year	Investment	Amount Invested (2011 Dollars)		Location
2012-01	2012	Well repair and replacement	$	3,870,000	Kandahar City (Zone 4) (see table 23)
2012-02	2012	Test wells in Zone 1	$	3,600,000	East of Kandahar City (Zone 1)
2012-03	2012	Test wells in Zone 2	$	900,000	Northwest of Kandahar City (Zone 2)
2012-04	2012	20 public standposts with tanks	$	7,600,000	See Figure 18
2012-05	2012	Well operation & maintenance	$	7,061,655	Kandahar City (Zone 4)
2012-06	2012	Well field development in Zone 1	$	36,737,000	East of Kandahar City (Zone 1)
2012-07	2012	Tanker trucking to initial 20 standposts	$	1,170,000	See Figure 18
2012-08	2012	Transmission pipeline from Zone 1 to city	$	38,000,000	See Figure 13
2012-09	2012	80 public standposts with tanks	$	30,400,000	To be determined
2012-10	2012	Tanker trucking to new standposts with tanks	$	2,340,000	To be determined
2012-11	2012	Phase 1-4 distribution network constuction	$	18,800,000	See Figure 21
2013-01	2013	Well operation & maintenance	$	10,298,475	Zone 1 well field
2013-02	2013	Well operation & maintenance	$	7,061,655	Kandahar City (Zone 4)
2013-03	2013	Tanker tucking to 100 existing standpost	$	5,850,000	To be determined (also see Figure 18)
2013-04	2013	100 public standposts with tanks	$	38,000,000	To be determined
2013-05	2013	Tanker trucking to new standposts with tanks	$	2,925,000	To be determined
2013-06	2013	200 normal density standposts	$	50,000,000	Construction phases 1-4, See Fig. 21
2013-07	2013	9 zone hub tanks	$	18,000,000	Construction phases 1-4, See Fig. 21
2013-08	2013	Distribution lines (hub tank to standpost)	$	111,000,000	Construction phases 1-4, See Fig. 21
2013-09	2013	Phase 5-7 distribution network construction	$	14,100,000	See Figure 20
2014-01	2014	Well operation & maintenance	$	10,298,475	Zone 1 well field
2014-02	2014	Well operation & maintenance	$	7,061,655	Kandahar City (Zone 4)
2014-03	2014	Tanker tucking to 200 existing standpost	$	11,700,000	To be determined (also see Figure 18)
2014-04	2014	8 zone hub tanks	$	16,000,000	Construction phases 5-7, See Fig. 21
2014-05	2014	200 normal density standposts	$	50,000,000	Construction phases 5-7, See Fig. 21
2014-06	2014	200 high density standposts	$	68,000,000	Construction phases 5-7, See Fig. 21
2014-07	2014	Distribution lines (hub tank to standpost)	$	99,000,000	Construction phases 5-7, See Fig. 21
2014-08	2014	Phase 8-10 distribution network construction	$	14,100,000	See Figure 21
2014-09	2014	Transmission pipeline from Dahla Dam	$	30,000,000	To be determined
2015-01	2015	Well operation & maintenance	$	10,298,475	Zone 1 well field
2015-02	2015	Well operation & maintenance	$	7,061,655	Kandahar City (Zone 4)
2015-03	2015	Tanker tucking to 200 existing standpost	$	11,700,000	To be determined (also see Figure 18)
2015-04	2015	220 normal density standposts	$	55,000,000	Construction phases 8-10, See Fig. 21
2015-05	2015	200 high density standposts	$	68,000,000	Construction phases 8-10, See Fig. 21
2015-06	2015	Distribution lines (hub tank to standpost)	$	123,000,000	Construction phases 8-10, See Fig. 21
2015-07	2015	10 zone hub tanks	$	20,000,000	Construction phases 8-10, See Fig. 21
2015-08	2015	Transmission pipeline from Dahla Dam	$	30,000,000	To be determined
2015-09	2015	Construct 1st increment of treatmnet	$	15,000,000	To be determined
2016-2020 - 1	2016 - 2020	Distribution lines to hub tanks	$	26,800,000	To be determined
2016-2020 - 2	2016 - 2020	19 zone hub tanks	$	38,000,000	To be determined
2016-2020 - 3	2016 - 2020	500 normal density standposts	$	125,000,000	To be determined
2016-2020 - 4	2016 - 2020	Distribution lines (hub tank to standpost)	$	228,000,000	To be determined
2016-2020 - 5	2016 - 2020	Construct 2nd increment of treatmnet	$	15,000,000	To be determined

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