Preface

Groundwater resources in the country are widely used for domestic, commercial and industrial purposes, water supply schemes and other purposes. Since 1970, groundwater extraction through dug wells, springs, and deep wells for water supply schemes (NWSDB and CBO maintained WSSs) has been increased. At present, more than 4000 rural and semi–urban WSSs are using groundwater as the water source.

It is identified that most of the PWSS are facing issues related to deterioration of water quality and reduction of pumping capacity, several years after commissioning. Also, groundwater sources in terms of quality and quantity has been impacted as a result of recent climatic changes. Therefore, well and aquifer problems and aquifer drainage are common issues of the groundwater intakes and they contributed for decreasing pumping capacity of intake wells and changing groundwater quality. The sustainable management of groundwater intakes through water safety plans are vital for continuous supply of groundwater with reliable water quality.

The identification of groundwater problems, assessment and preparation of mitigation strategies are essentials for groundwater management systems and for the preparation and implementation of Water Safety & Security Plans (WSSP) which includes groundwater sources and intakes of PWSS. However, literature related to the groundwater issues and practices for overcoming issues relevant to country situations are limited. Therefore, this document "Guideline for Management of Groundwater Sources for Piped Water Supply Schemes" will be very useful for the entire Operation & Maintenance officers and staff of NWSDB; relevant staff of DNCWS, Water CBO Executive committees including operators, and others stakeholders who extract groundwater using electric water pumps. The officers and staff in Groundwater Section in Head Office as well as in RSCs will also follow this guideline and provide the required guidance, assistance and services to implement it. Also, we need to work together to sustainably manage this precious resource.

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Assistant General Manager(Groundwater)
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Massage from the Chairman,
National Water Supply and Drainage Board

'Serving the Nation by providing sustainable water and sanitation solutions ensuring total user satisfaction' is the Mission of the National Water Supply and Drainage Board.

The Sri Lanka Government's National Policy Framework of "Vistas of Prosperity and Splendour" envisages that every household shall be provided with clean and safe drinking water. Going forward, in order to reach this goal, as the National Agency responsible for providing safe drinking water to the people in the country, we have to overcome challenges and barriers related to the water supply sector. It is my firm belief that identification, assessment, giving technical solutions, and maintaining proper documentation of these issues would ensure a good understanding and help in overcoming them in a systematic and cost effective manner. In the process of moving forward with technical developments, a proper system of guidelines is vital for smooth running and management of the water supply systems.

I would like to believe this guideline will be helpful in maintaining the smooth functioning of the numerous groundwater based water supply schemes of the country which in turn will render utmost support to accomplish the mission of NWS&DB and the National Policy "Water for all" by 2025.

Mr. Nishantha Ranatunge
Chairman
National Water Supply and Drainage Board

Massage from the General Manager,
National Water Supply and Drainage Board

Being the most extracted raw material of the world, groundwater plays an important role in sustaining life and maintaining human activities on earth. As almost 50% of the world's drinking water need is fulfilled by groundwater, it is very apparent that it reflects the need for conserving this source for sustainable use. This need is further enhanced with the current global climatic variations, drastically shrinking the available water resources. It is noted that in developed countries, proper management of groundwater resources is undertaken by the regulatory bodies and supplying authorities, eventually reducing mismanagement and improving the lifetime of such sources.

Groundwater resources in Sri Lanka are estimated at about 7,800 million m^3 per year. Groundwater is the major source of water especially in rural areas and it is estimated that about 72% of the rural population relies on groundwater for domestic use. In this context, it is essential to build up a proper management system which is guided by the methods adopted to the country's needs under scientific criteria.

This "Guideline for Management of Groundwater Sources for Water Supply Schemes" prepared by the Groundwater Section, NWS&DB, is a novel publication of its kind in Sri Lanka and is expected to guide all the authorities, governing bodies and management on how to utilize this invaluable resource in a sustainable manner for the current population and future generations to come.

Eng. Thilina S. Wijetunge
General Manager
National Water Supply and Drainage Board

Massage from the Addl. General Manager (WR) National Water Supply and Drainage Board

Groundwater is extensively used in Sri Lanka today, for agriculture, domestic use and industry/tourism and plays an important role in supply of drinking water to the communities especially in rural and suburban areas. Currently, more than 75 groundwater based water supply schemes operate within the NWSDB extracting more than 80000 m^3/day of groundwater. In addition to these, numerous community-based water supply schemes are also operating with groundwater sources.

It has been noted that the deterioration of water quality and reduction of pumping capacity of groundwater would occur several years after commissioning. In addition to the global climatic changes it is inferred that improper management, lack of routine maintenance and delay in taking proper precautionary measures, contribute mainly for these sources to drop their performance and reduce their lifetime. Therefore, it is high time we come up with a proper groundwater management strategy in the country. It is with a great sense of pride I would like to mention that the "Guideline for Management of Groundwater Sources for Water Supply Schemes" is a good initiative in this regard and with its capacity for adaptation & improvement by relevant people. This guideline will be a great platform to develop and make use of strategies for smart groundwater system management in the country.

Eng. I. V.W. Ediriweera
Addl General Manager (Water Reclamation)
National Water Supply and Drainage Board

Massage from Addl. General Manager (S/S) National Water Supply and Drainage Board

As the demand for drinking water increases with the growing population, extraction of potable water has also increased exponentially. However, due to the limited resources availability and increasing threats to these resources, it has opened up a discussion on ways to protection and sustainable management of groundwater sources. Water Safety and Security Plans (WSSP) is one of the most appropriate and widely used practices worldwide, initiated by the World ealth Organization. WSSP aims to ensure safe drinking water through a rigorous assessment of risks and managing these risks to achieve a safe water supply from catchment to consumer. As per its definition, the WSSP addresses the safety of water from the 'catchment' to 'consumer' which I believe this guideline also touches upon it.

Hence, the "Guideline for Management of Groundwater Sources for Water Supply Schemes" will be a good tool to assess the state of a groundwater source, identify potential threats, not only locally but also on a regional scale and attend to these issues in a systematic, scientific manner. The expected outcome of this great effort is to take action to mitigate the risks and work toward a sustainable supply of safe drinking water for furthering the activities of WSSP to the success.

Eng. K.P.R.S. Samarasighe
Addl General Manager(S/S)
and
Chairman (Water Safety Adversary Committee)
National Water Supply and Drainage Board

Acknowledgement.

Assistant General Manager (Groundwater) and Water Safety Plan Advisory Committee wishes to express its sincere appreciation to Mr. Nishantha Ranatunge, Chairman and Mr.Thilina.S. Wijetunge, General Manager of the National Water Supply and Drainage Board (NWSDB) for arranging necessary approval through Project Appraisal Committee (PAC) for the publishing of this Guideline.

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Abbreviation

CBO	Community Based Organization
CRWSSP	Climate Resilient Water Safety and Security Plan
EPA	Environmental Protection Agency
MSL	Mean Sea Level
NWSDB	National Water Supply and Drainage Board
DNCWS	Department of National Community Water Supply
PWSS	Piped Water Supply Scheme
SLS	Sri Lanka Standard
TOT	Time of Travel
US	United State
WHO	World Health Organization
WHPA	Wellhead Protection Area
WRB	Water Resource Board
WSP	Water Safety Plan
WSSP	Water Safety and Security Plan
ZOC	Zone of Contribution
ZOI	Zone of Influence

Guideline for Management of Groundwater Sources for Piped Water Supply Schemes.

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EXECUTIVE SUMMARY

Groundwater in the country is used for many rural and semi urban piped water supply schemes after assessment of the pumping capacity of a well or a well field as per the agreed pumping test procedure with due consideration for the hydrogeological, general climatic, and land use conditions. The daily groundwater extraction of 90% of these existing PWSS varies between 40 and 500 m^3.

It is identified that most of the PWSS are facing issues related to deterioration of water quality and reduction of pumping capacity, several years after commissioning. The pumping capacity reduction of intakes occur as a result of well and aquifer problems. They could be assessed based on the behavior of specific capacity with time. The continuous reduction of specific capacity will lead to the reduction in useful life span of the well. In addition to quantity, water quality deterioration is also a major issue faced in PWSS. These problems are complex but are directly related to natural processes, man-made activities and limited understanding of hydrogeological behavior incurred due to pumping.

This guideline adheres to the Water Safety and Security Plan (WSSP), which has been identified by the World Health Organization (WHO) as one of the most effective water supply management tools and recommends it for PWSS to ensure a safe water supply with proper planning, design, implementation, documentation and monitoring. The WSSP process is further strengthened with a rigorous process of auditing.

This guideline emphasizes the factors which a groundwater source depends on and which are needed to be carefully assessed to identify the actual condition of that particular source. The annual rainfall variation and its effects are categorized with respect to the change and effect to the natural recharging process. This, together with groundwater extraction is used to assess the condition of the aquifer and the need for artificial recharge. Lack of proper well design and operational practices are major causes for the deterioration of well performance. Therefore, it is important to monitor the specific capacity of an intake in order to identify its trends and take precautionary actions. Groundwater quality deterioration is caused either from the changes in groundwater environment or due to the contamination of the sources. The former includes factors such as over extraction, decreasing recharge, climatic

change effects, and surface and sub-surface physical and chemical changes. Changes in the chemical environment is hard to prevail but well maintenance, management of groundwater storage and management of groundwater withdrawal can avoid adverse groundwater quality deterioration.

Contaminated sources causing groundwater pollution should be managed through a good network of monitoring and quick precautionary actions, mainly achieved by the implementation of Wellhead Protection Areas (WHPA).

Implementation of this guideline is followed by a process of monitoring and identification of issues through collection and analysis of data. A stepwise process is introduced for the identification of potential hazards, assessing and prioritizing the risks, identifying of existing control measures and assessing their effectiveness, ultimately allowing to select the most effective counter measures.

Chapter 1

Guideline for Management of Groundwater Sources for Piped Water Supply Schemes.

1.0 Introduction

The extraction of groundwater for the piped water supply schemes (PWSS) in Sri Lanka has been started since 1970. At present, more than 4000 rural and semi urban PWSS are using groundwater sources such as springs, dug wells, wells with laterals, shallow and deep tube wells. Groundwater intakes consists of one well or a well field with similar mode or different modes. These intakes are constructed on different aquifer systems and also in different climatic zones of the country. Some groundwater intakes are used only during dry periods while others are in operation throughout the year. The daily groundwater extraction of 90% of the existing PWSS varies between 40 and 500 m^3.

The presence of higher concentration of iron, manganese, hardness, fluoride, alkalinity, and salinity (sometimes due to intrusions) etc. in groundwater causes quality parameters to exceed the SLS 614:2013-drinking water quality parameters requirements. These parameters often create water quality issues that are different from water scheme to scheme. In some cases, enrichment of water quality parameters is limited only to the dry period. In addition, most of the PWSS are facing issues such as deterioration of water quality and reduction of the pumping capacity, several years after commissioning.

The reduction of pumping capacity is a very common issue in most of the groundwater intakes due to the depletion of the groundwater table. Some intakes show a continuous reduction of pumping capacity while others show only seasonal reductions. The pumping capacity reductions of intakes can be attributed to decrease in the groundwater flow to the intakes as a result of well and aquifer problems. The occurrence of aquifer problems is mainly due to climatic consequences and man-made issues. The well problems are due to increased well losses in well structures (well screen and fractures) and operational issues. The specific capacity (pumping rate/drawdown) is the common measure of well performance and continuous reduction of specific capacity will lead to reduction of the useful life span of the well. The average lifetime of most of groundwater intakes of the country is about 10-15 years which is very short compared to that of the developed countries which is about 40 years.

The processes involved in water quality deterioration and reduction of specific capacity are complex though they are directly related to natural processes, man-made activities, and limited understanding of hydrogeological behavior incurred due to pumping. Identification of these potential issues, assessment, and their mitigation are timely interventions and necessary to be addressed urgently.

Water Safety Plan (WSP) has been recognized and recommended as the most appropriate and entrusted water supply management tool by the World Health Organization (WHO) to ensure consistently safe water supply. The WHO has further expanded the scope of WSP to accommodate the challenges due to climate change impacts in the water sector in 2017. In the water industry, a Water Safety and Security Plan (WSSP) is a comprehensive approach from the catchment to the customer. It comprises a system assessment and design, operational monitoring, and management plans, including documentation and effective communication. The elements of a WSSP build on the multiple-barrier principle, the principles of hazard analysis and critical control points and other systematic management approaches.

Above aspects are discussed below under the management of groundwater sources including water safety and security plans (WSSP) to ensure reliable water supply in terms of quality, quantity and cost effectiveness.

In order to implement a proper groundwater management system and associated water safety and security plans (WSSP), related activities must be addressed during planning, construction, and operational phases of the groundwater intakes. Therefore, improvement of groundwater quality and maintaining optimum and sustainable yield of intakes are challenging tasks in groundwater management systems and water safety and security plans (WSSP) implementation.

Reasons for water quality deterioration and reduction of specific capacity of intakes in the water supply schemes of the country can be categorized as below.

Reasons for water quality deterioration	**Reasons for reduction of specific capacity**
Changing of groundwater environment due to natural (climatic changes) and man-made activities	Increase in well loss due to blockage of well structure (well screens and fractures) by sediments and scales. Carbonate and iron incrustations are common in the wells.
Contamination by pollution sources at intakes, immediate surroundings, and recharge areas.	

The continuous monitoring of water quality, specific capacity and related operational details are crucial in identifying the causes and possible consequences. Therefore, it will be useful for designing, and implementation of mitigation strategies to maintain a higher productiveness in terms of quality and optimum yield of the groundwater based intakes.

The development of guidelines for identification and assessment of issues, and mitigation strategies are essential and are included in this document for adopting in groundwater management systems and implementation of WSSP for groundwater intake of PWSS.

2.0 Guideline Objectives

This guideline is developed for identification of issues, assessment and preparation of mitigation strategies which are essentials for groundwater management system and preparation and implementation of Water Safety & Security Plans (WSSP) for groundwater sources and intakes of PWSS.

The target group for this guideline is the entire Operation & Maintenance officers and staff of NWSDB; relevant staff of DNCWS, Water CBO Executive committees including operators, and others stakeholders who extracting groundwater by using water pumps.

The officers and staff in Groundwater Section in Head Office as well as in RSCs will also follow this guideline and provide the required guidance, assistance and services to implement it.

3.0 Hydrogeology and main aquifers system of the Country

Geologically, about 90% of the country's land is underlain by hard rock where the aquifers are not highly productive due to the low porosity. However, fractured aquifer systems depending on the hydrogeological set up produces potential zones of this basement rock of the country. The rest of the area, mainly north and northwestern parts are composed of limestone with higher productive aquifer formations due to relatively higher porosity.

Six (06) main aquifer types have been identified and demarcated in the country (Panabokke and Perera, 2005) based on the studies carried out over the last 25 years mostly by the Water Resources Board (WRB) and the National Water supply and Drainage Board (NWSDB). Each of these aquifers have distinctive characteristics, specific issues and needs. Therefore, each aquifer will require specific management strategies and actions for the development and sustainable management.

The main aquifer types are; (i) shallow karstic aquifer, (ii) deep confined aquifer, (iii) coastal aquifer, (iv) alluvial aquifer, (v) shallow regolith aquifer of hard rock and fractured hard rock aquifer, and (vi) lateritic aquifer. The deep confined aquifers and most of fractured hard rock aquifers are naturally protected against pollution. The impact of anthropological activities is frequently observed in the shallow regolith aquifers, coastal sandy aquifers, and shallow karstic aquifers in Jaffna (Panabokke and Perera, 2005).

In addition to the main aquifers (Figure 3.1), numerous small groundwater pockets are found throughout the country (IGES, 2007). Seven distinct groundwater basins have been identified and mapped within deep confined aquifer regions and are named as Mullaitive, Mulankavil, Paranthan, Murunkan, Kondachchi, and Wanathavilluwa basins (Figure 3.2). Groundwater in hard rock formation is found in the weathered formations and the fractured zones in hard rock.

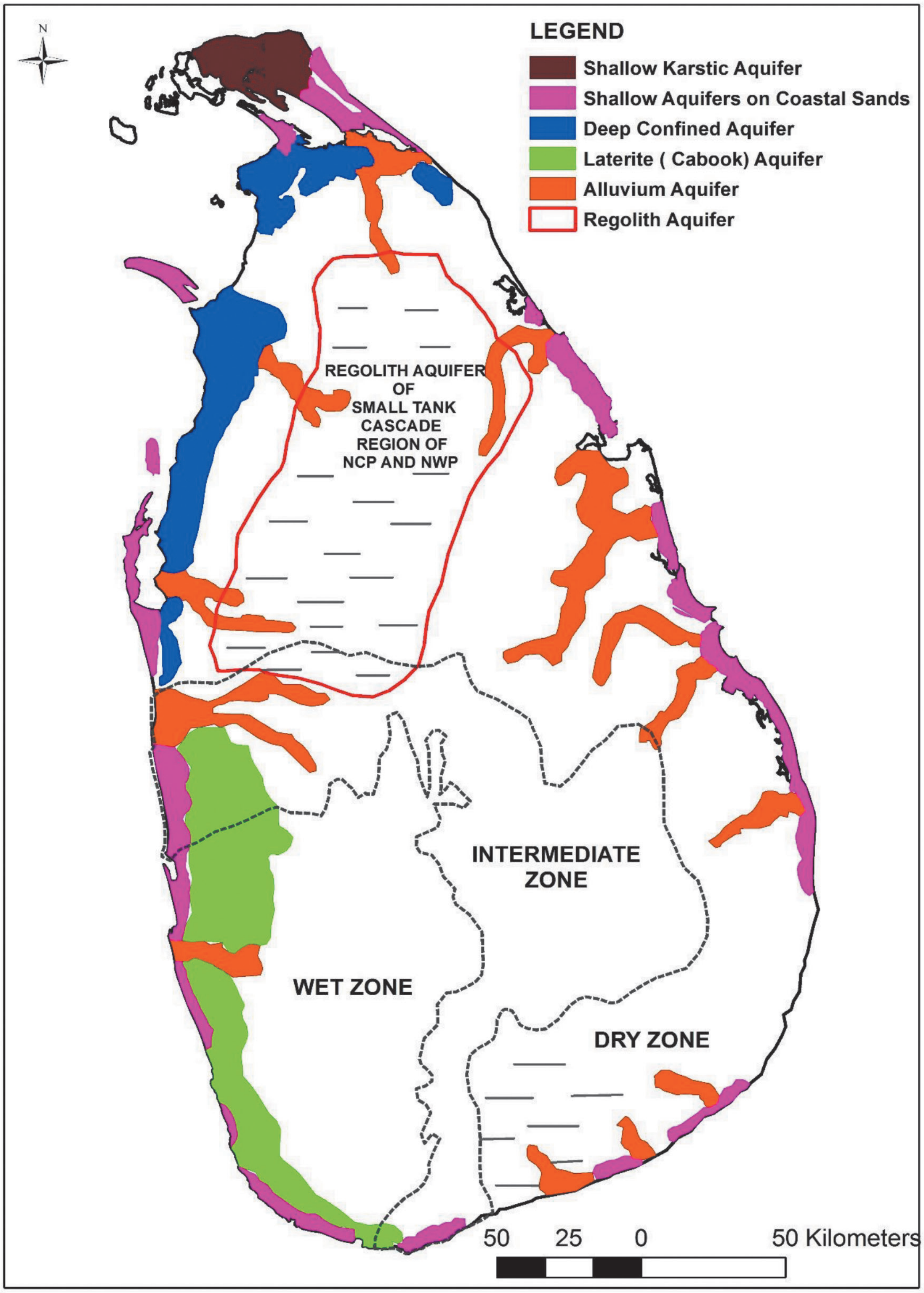


Figure 3.1: Map of different aquifer types in Sri Lanka (after Panabokke and Perera, 2005)

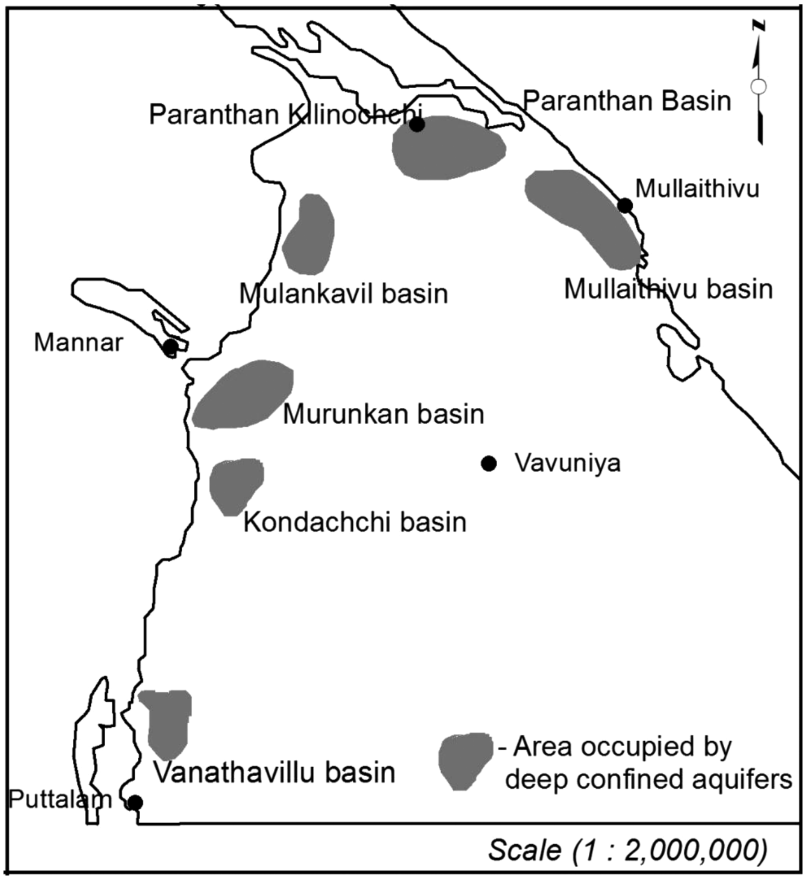


Figure 3.2: Deep Confined Aquifers of the Sedimentary Limestone and Sandstone Formations

4.0 Status of groundwater used for piped water supply schemes

Groundwater resources in the country are widely used for domestic, commercial and industrial needs, water supply schemes and other purposes. In areas where surface water and pipe borne water systems are not available or not reliable, groundwater provides industrial and commercial users more reliable water supply of water. Most of the industries in the country depend heavily on deep wells where groundwater is safe and of good quality, and can be self-managed (Panabokke and Perera, 2005). Also, groundwater is the most popular source for bottled water manufacturing industry in the country due to its favorable quality.

Presently, groundwater is continuously extracted for NWSDB maintained and CBO managed WSS and details are presented in Figure 4.1 and 4.2. Most of CBO managed WSS are operating under guidance, backup support, and monitoring of DCNWS. The provincial distribution of groundwater sources of WSS (NWSDB and CBO) are given in the table 4.1.

Table 4.1: Groundwater sources used for the WSS maintained by NWSDB and CBOs

Province	Number of WSSs maintained by NWSDB		Number of WSS maintained by CBOs (Source:www.rwss.lk, 2020)	
	No of WSSs with groundwater intakes	No of wells/ groundwater sources	No of WSSs with groundwater intakes(A)	No of wells/ groundwater sources(B)
Central	10	24	291	414
Sabaragamuwa	2	3	293	430
Southern	10	20	351	483
Uva	7	13	455	611
North	20	84	71	75
Western	6	21	265	415
North Central	14	63	236	387
North Western	8	25	429	761
East	3	19	38	46
Total	80	272	2429	3622

The most common problems of many PWSS are decreasing of pumping quantity and deterioration of water quality in pumping wells several years after commissioning. Both scenarios are contributing for the decrease of life span of the wells. It is noted that attempts have not been made for the well development at the correct time and therefore, poorly performed wells have been abandoned frequently. The construction of new replacement wells is the common remedy for abandoned wells in the country.

The findings from the recently conducted analysis of existing groundwater sources in NWSDB maintained WSSs; except those within coastal sand aquifers, are given below in table 4.2.

The main controlling factor for the sustainable the groundwater extraction in coastal aquifers is the maintenance of groundwater level of the aquifer.

Table 4.2: Conditions of the existing groundwater sources in NWSDB maintained WSSs

Well condition	Average life span of the well(year)	Remark
Pumping rate is less than the recommended rate with good water quality.	25	Frequency of maintenance is naturally low.
Pumping rate is less than the recommended rate with high iron concentration.	15	Frequent well development is needed to increase the well life
Pumping rate is more than the recommended rate with good water quality.	20	Controlling the pumping rate is necessary to increase the well life
Pumping rate is more than the recommended rate with high iron concentration.	10	Frequent well development and controlling pumping rate is necessary to increase the well life
Over pumping wells.	8	Life time of some wells is less than 5 years

Mostly, groundwater quality of an aquifer systems is inherent to that particular aquifer system but may show seasonal variation with climatic conditions. In addition, groundwater quality could be affected due to the pollution sources and changing groundwater environment. Some examples are deterioration of groundwater quality; mainly nitrate, electrical conductivity and hardness in Jaffna Peninsula and Kalipinya area due to the excessive application of agrochemicals and uncontrolled abstraction of groundwater.

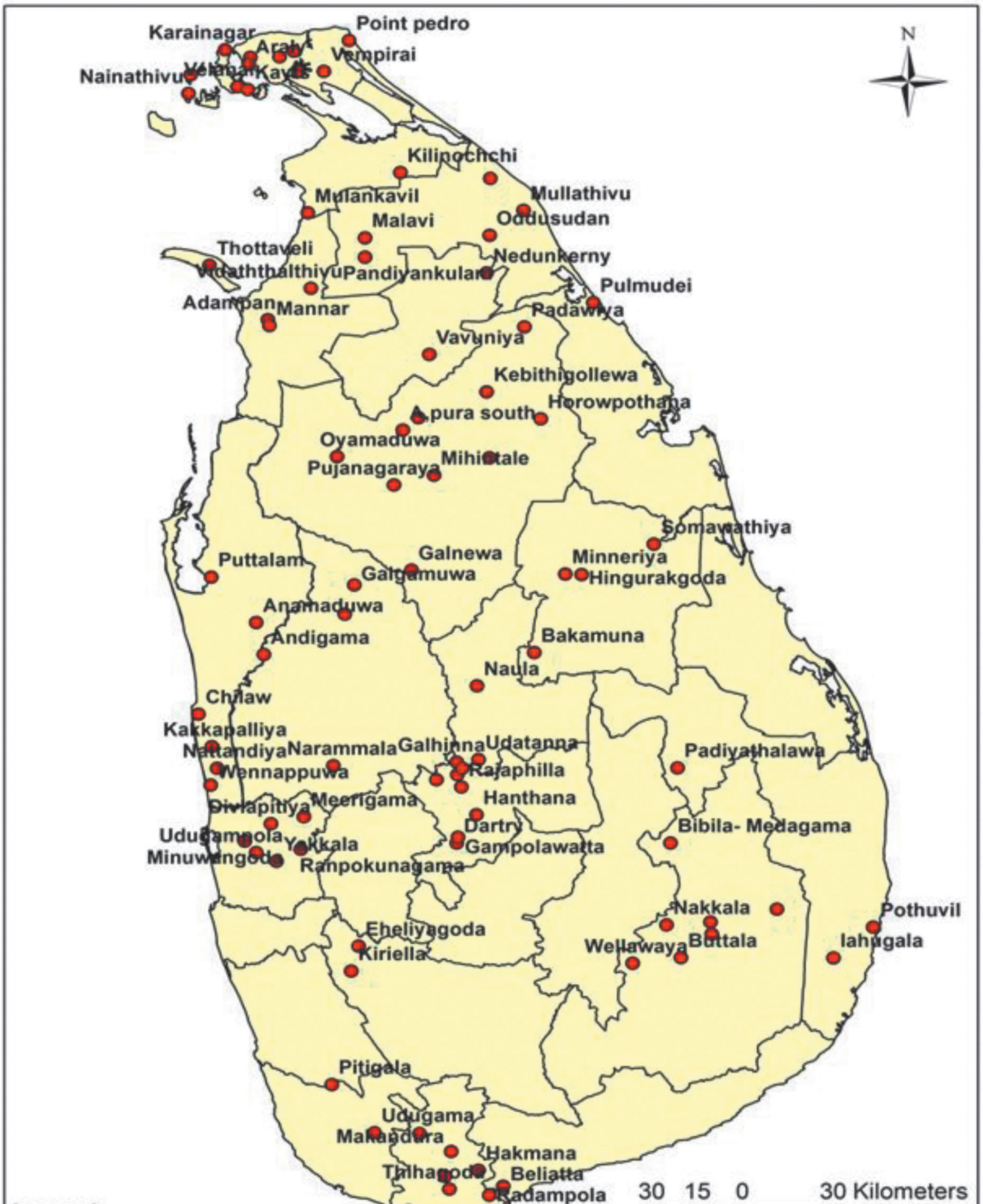


Figure 4.1: Groundwater intakes of NWSDB maintained WSSs.

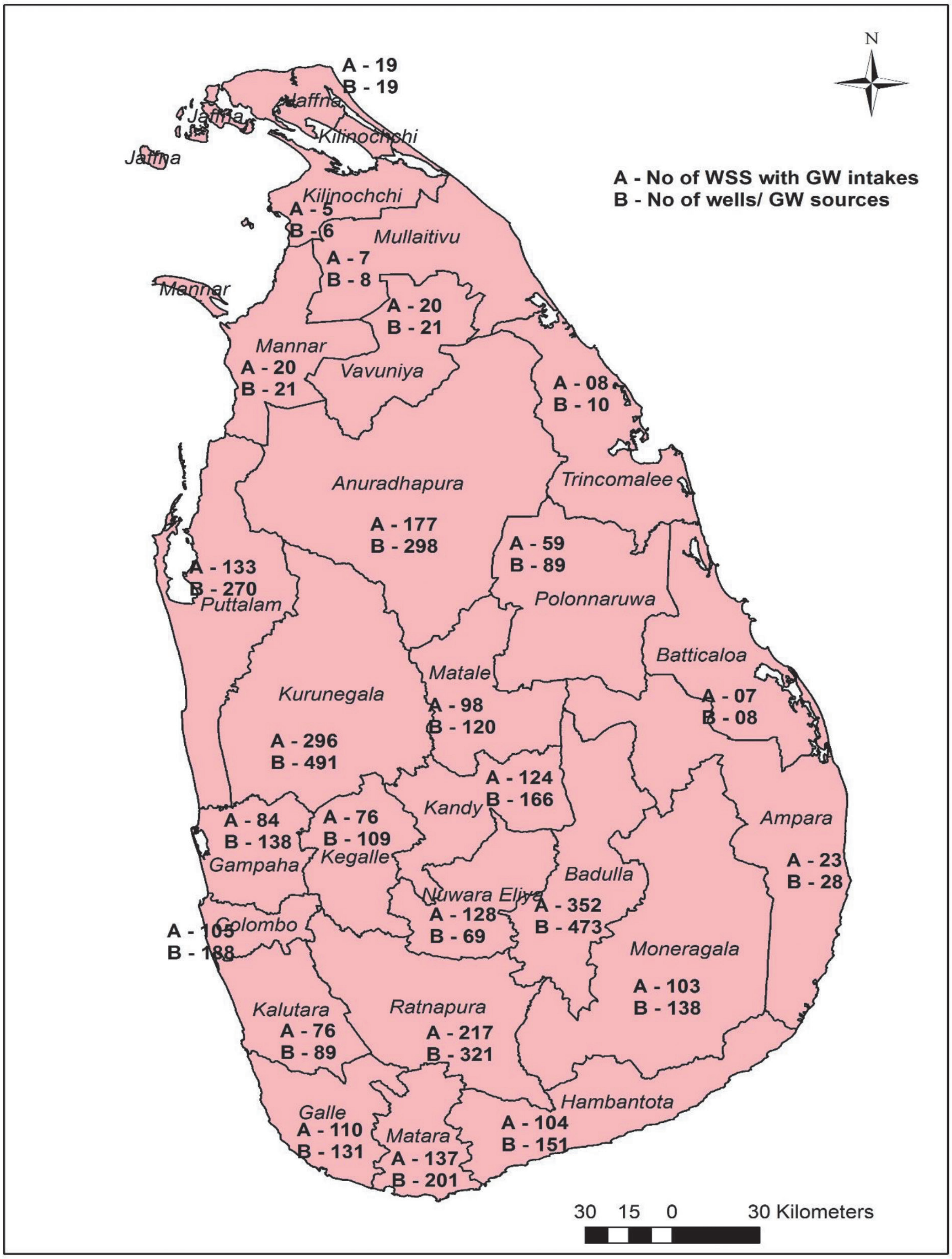
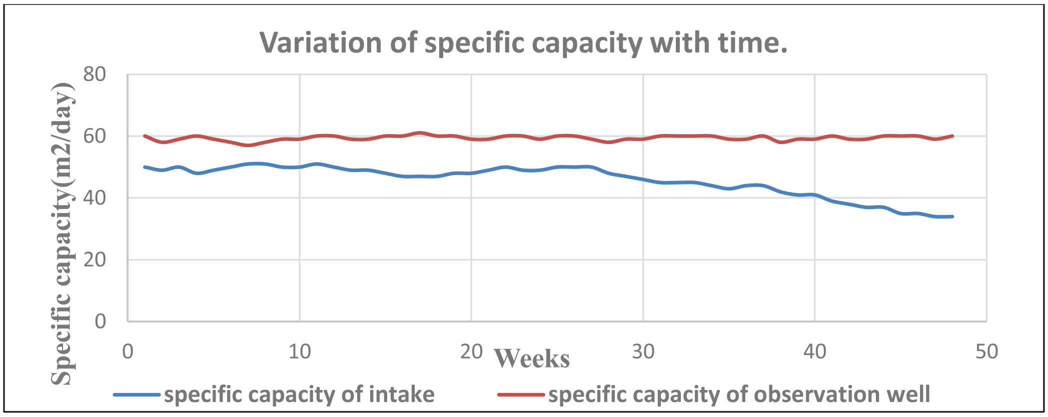


Figure 4.2: Groundwater intakes of CBO maintained WSSs (Source:www.rwss.lk, 2020)

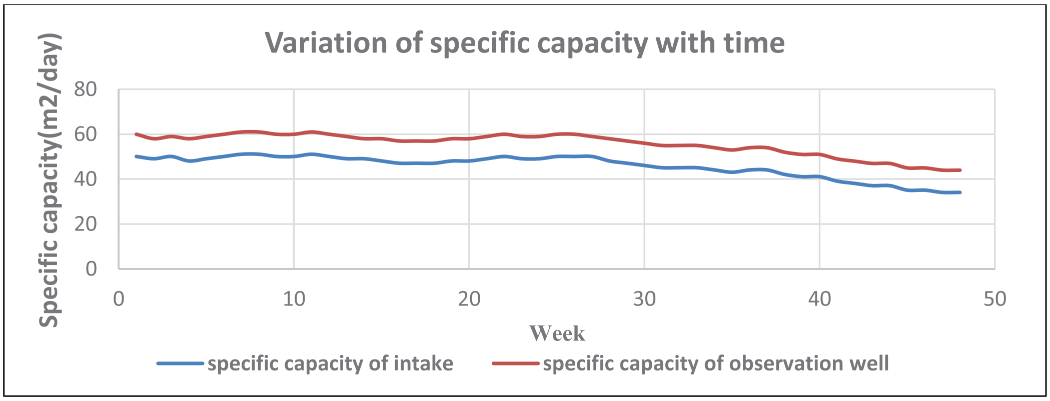
Chapter 2

5.0 Influencing factors for sustainable groundwater extraction

At the initial stage of the well construction, an assessment of pumping capacity (optimum yield) for the groundwater sources of PWSS was carried out as per the agreed pumping test procedure with due consideration for the hydrogeological, general climatic, and land use conditions. (See Annex:1) The optimum yield is affected with time due to natural and manmade factors. They are changes in the hydrogeological environment in the vicinity and the recharge zone, climatic condition, construction weaknesses, and operational inefficiencies. The prediction and identification of above issues are complex and sometimes involve a multitude of all above factors. However, presence of observation boreholes closes to the intake in the same or with similar hydrogeological unit is useful to monitor and predict the anticipated quantity and quality issues. Two such examples are given below in Graph:5.1 and 5.2.



Graph 5.1: Reduction of specific capacity due to screen clogging (Well problem)



Graph 5.2: Reduction of specific capacity due to false clogging (Aquifer drain or reduction in saturated thickness in the aquifer).

The variation of pumping capacity of groundwater intake due to climate, construction issues, operational matters, and manmade issues are described in the sections below.

5.1 Annual rainfall variation and its effect on groundwater extraction

Generally, there are three stages (1st stage, 2nd stage, and 3rd stage) of groundwater environments commonly identified in many groundwater intakes concerning the variation of the annual climatic cycle (Dillon, P.2009). The time taken for reaching the particular stages of each intake is different and entirely depends on recharging conditions.

1st Stage

When pumping wells are commissioned, natural replenishment from the annual climatic cycle is helpful to recover the storage loss and aquifer drainage loss. Any significant impact from other groundwater users in the area, recharge from surface water bodies, and the effective groundwater reservoir is not to be seen at this stage. This is because groundwater withdrawal and recovery are balanced. However, pumping quantity of the wells may fluctuate between dry and wet period of the year due to seasonal fluctuation of groundwater level. Generally, this fluctuation is natural and dependent only on the annual climatic cycle.

The subsequent higher groundwater productions from the WSS intake well or withdrawal of water from the aquifer by new intakes outside can unbalance the groundwater environment equilibrium.

2nd Stage

This stage can occur when annual rainfall drops and deviate from the average yearly rainfall of the recharging area. Therefore, withdrawal of groundwater must be done by giving due attention to the climatic conditions in order to protect the groundwater sources in terms of quality and quantity. Under this situation, groundwater recharge to the pumping well could drop and groundwater extraction from the pumping well must be regulated to balance recharge and protect the groundwater environment. In some locations, additional wells can be constructed in the same area beyond the radius of influence, to meet the deficit.

The declining trend of groundwater level, depletion of stream flow, depletion or disappearing flows of springs, and reducing of well yield in the pumping well in dry years than the average years are main indications for negative changes in the groundwater environment. However, in wet years, groundwater environment may temporarily reach to that of the initial stage.

In this stage, re-evaluation of the groundwater system is essential and groundwater pumping from the existing intake well needs to be rescheduled with new and appropriate discharges. Further, additional wells can be constructed in the areas where there is no interference to the existing pumping wells, to meet the water shortage. It is also necessary to study the possibilities to improve the aquifer system (artificial recharge) and to explore alternative water sources.

3rd Stage

If groundwater development is continued disregarding the indications, the groundwater environment reaches the 3rd stage. During the 3rd stage, reduction of groundwater storage and well yield, and changes in chemical water quality could be expected even during wet years. There will be no provision for the restoration of the groundwater environment naturally. The only solution is introducing an artificial recharging system to improve the groundwater storage within the aquifer system which again depends on the vulnerability of the site.

Groundwater environment of intake areas are detrimentally affected as a result of climate change consequences such as long droughts and intense rains but in short spells. However, at present, monitoring data on groundwater level and groundwater quality are scarce and accurate predictions on groundwater environment are thus difficult.

5.2 Well design and intake construction effect the groundwater extraction

Some well problems are directly related to the construction weaknesses. They are sand yielding to the well through interface between rock and overburden or/and screens or fractures, rock falling to the well, and entrance velocity issues due to the use of improper screen materials for the well. Therefore, suitable intake design and appropriate construction methods should be selected for maximum utilization of the aquifer and to control the well and aquifer pollution as per the hydrogeological conditions of the site.

For the borehole: Angular space between drilled hole and casing up to 5 m depth below ground level should be sealed using cement grout or clay as a sanitary seal (as cited by Xu, Y. and Braune, E., 1995a). About 2 m radius and 0.5 height circular shape concreate collar (0.2 m below the ground) around the borehole should be constructed to ensure drainage away from the borehole (as cited by Xu, Y. and Braune, E., 1995a).

Also, additional 5 m depth should be drilled with same diameter after striking the main fractured zone for accumulation of fine materials added to hole along the fractures and interface between rock and overburden should be sealed by using cement grout to isolate the overburden and rock formation. In addition, standard materials (screen and casing materials) should be used during the construction to avoid the entrance velocity issues and damage of line materials.

For Dug wells and Spring boxes: Angular space between excavated hole and lined hole up to 2 m depth below ground level should be sealed and compacted using concreate or clay as a sanitary seal. About 2 m buffer area around the well is used to place the concrete collar to ensure drainage away from the area immediately around the dug well or spring box.

5.3 Operational practices affecting the groundwater extraction

The continuous monitoring of the specific capacity of the groundwater intake is necessary to observe overall well and aquifer performance with time. The specific capacity of intake reduces with time and it varies from intake to intake. The examples for the reduction of specific capacity of intakes are given below.

> **Example (1):** If the annual reduction curve of the specific capacity of the intake well is a downward trend and the change is still less than 20% of that at the initial stage; the intake is not capable to produce the recommended extraction due to the decreasing well performance. The identification of causative factors and immediate remedial actions are needed to fully rectify this issue before reaching a serious level.
>
> **Example (2):** If any reduction of the groundwater level and the discharge of the intake has not been noticed, the intake may be recharging from other sources in addition to the annual climatic cycle. However, if a reduction of the specific capacity is noticed after several years without any change in the water level of the recharging source; this is also due to the decrease in well performance. Therefore, identification of causes for such decrease and immediate remedial actions are needed to rectify the issue before reaching a serious level.

The identification of its reduction at the initial stage is vital to understanding the influencing factors and implementing migratory measures for converting the intake to the original stage.

If the annual reduction of specific capacity is between 20% - 50%, and the intake is in a hard rock aquifer; intake well may be difficult to recover or may not be entirely recoverable. If the reduction of specific capacity is greater than 50%, re-use possibilities of the intake are very limited and construction of a new intake will become necessary to resolve the issue. In very rare cases, natural recovery of groundwater system may takes place several years after abandoning the intake well due to improvements from recharge.

5.4 Man-made activities including interference from other groundwater users

The sudden and irregular variation of groundwater level and pumping quantity of the groundwater intake can occur due to the multiple user interference and the resulting depletion of the recharging source. The coordination, sharing, and enforcing of regulatory mechanisms, shall be more beneficial to overcome such issues.

6.0 Groundwater quality deterioration.

The common reasons for groundwater quality deterioration are changes to the groundwater environment and groundwater contamination from pollution sources. These different scenarios have to be handled separately under the groundwater quality management system and WSSP implementation.

6.1 Groundwater quality deterioration due to the changing groundwater environment

Groundwater deterioration occurs due to several reasons such as over-extraction, decreasing recharge as a result of changes in land use, climate change, surface and subsurface changes associated with unplanned exploitation of earth materials, groundwater mixing, and leaching of chemical constituents from weathering process, etc.

The chemical weathering and leaching of chemical constituents of rock and soil to groundwater is the natural process in the saturated and vadose zones. The concentration of chemical constituents in groundwater can also seasonally fluctuate due to climatic variations and groundwater flow changes. The groundwater quality maps are useful to identify the critical water quality areas in the subsurface. Remedial measures other than suitable treatment of water to reduce the concentration of such chemical constituents are not practical.

The over-extraction is very common in many groundwater intake wells. It will lead to continuous lowering of groundwater levels in pumping well and groundwater quality changes. Often, groundwater quality changes are limited only to some chemical parameters. Some examples are given below. On the other hand, a change in water quality during the pumping period is an indication of reducing the well performance as well as lifetime of well.

Example 1: Enrichment of iron and manganese in pumping well as a result of a change of Eh-pH in the groundwater system.

Example 2: Enrichment of salinity due to sea water intrusion in pumping well due to up corning of freshwater –seawater interface.

Example 3: Enrichment of alkalinity and hardness during the pumping well would be a result of the incongruent dissolution of silicate minerals and carbonate minerals and also due to increasing partial pressure of Carbon Dioxide.

The well maintenance, management of groundwater storage, and management of groundwater withdrawal should be properly executed to control the possible groundwater quality deterioration due to changing groundwater environment.

6.2 Groundwater quality deterioration due to the contaminant sources

The groundwater of the pumping well could be contaminated by many different sources such as leachate from landfills, agrochemicals, septic tank systems, gasoline, road/traffic contaminants etc in the intakes, immediate surroundings, and recharge areas. Once groundwater is degraded by contamination from human activities, its usability is greatly reduced.

The main factor to be considered for the vulnerability due to contamination is the time lag between the entry points of a particular contaminant to reaching the groundwater system and its detection at the water supply well or at monitoring points. Therefore, vulnerability to groundwater contamination and health implications to the users must be identified and controlled by using appropriate wellhead protection areas (WHPA) to secure the water supply intakes.

The identification of potential hazards, inventorying them, assessing of the risks, and mitigation or controlling significant risks to the well and to its immediate surrounding are included under WSSP and direction to control the potential hazards is given in Annex:3.

7.0 Wellhead protection and related best practices.

The Wellhead Protection Area (WHPA) is defined as "the surface or subsurface area surrounding the well or well field supplying a public water system, through which contaminants are reasonably likely to move toward and reach such well or well field" (U.S. Environmental Protection Agency – US- EPA, 1987). WHPA represents a surface projection of the entire 3-D capture area from which water is pumped from the groundwater intake.

Generally, WHPA is divided into three zones according to Time of Travel (TOT) for effective management of different potential risks that could be expected to water quality of intake from various types of microbiological and chemical constituents as indicated below.

- Zone 1(Less than 2 years TOT): Land use is to be managed to minimize all possible water quality risks including bacteria and viruses.
- Zone 2 (2 to 10 years TOT): Land use is to be managed to minimize risks from chemical constituents. Bacteria and viruses may still be a concern.
- Zone 3 (10 to 25 yeas TOT): Land use is to be addressed to minimize risks from hazardous contaminants.

In the initial stage of groundwater development, the establishment of the above three zones on the ground will be difficult for a country like Sri Lanka due to the lack of a suitable legal framework. Therefore, conveying the massage to the community organization and necessary dialog between involved stakeholders and institutions for the protection of groundwater quality is vital until the establishment of such a framework. It is more realistic and advisable to start this process by allocating one wellhead protective zone.

The size and shape of the wellhead protection zones are influenced by pumping rate, porosity, water cycle, aquifer types, hydraulic conductivity, flow direction, hydraulics gradient, orientation and density of fractured zones, and geology of the area as describe below.

Water cycle: It is to understand where groundwater comes from and how it flows through the subsurface (recharge and discharge area) before deciding what area is to be protected.

Aquifer Types: Aquifers can be divided into two board categories. A confined aquifer is overlain by a geological unit of lower hydraulic conductivity or impermeable geological formation, while an unconfined aquifer has water table as its upper boundary. Application of WHPA for unconfined aquifer is easy while it is very complex for the confined and fractured aquifers.

Groundwater flow direction and its changes: The knowledge of groundwater flow and groundwater level map for the particular area will be very useful for the application of some well delineation methods. The development of potentiometric surface map will be useful for the confined aquifer system. If groundwater is withdrawn at a relatively higher rate than aquifer can supply water to the well, the dynamic water table surrounding the pumping well is defined as the *cone of depression.*

Pumping rate: The selection of optimum pumping rates for well and well field will be useful to control the zone of contribution. This will be established only after a pumping test. (See Annex 1)

Hydraulic conductivity and hydraulic gradient: The hydraulic conductivity and hydraulic gradient of the aquifer control the velocity of groundwater flow towards well during the pumping of well or well field. The low hydraulic conductivity geological units will provide more protection for contamination than high hydraulic conductivity geological units.

Orientation and density of fractured zone: The porosity as well as hydraulic conductivity is relatively high along the fractured zones than the surrounding formations. Therefore, demarcation of secondary porosity rich zone around the pumping well or well field will provide the accurate picture for delineating of WHPA.

The several criteria such as distance, drawdown, time of travel, and flow boundaries are commonly used to delineate the WHPA by using different techniques (See Table:7.1). Some criteria are not based on hydrogeological data of the particular area and some methods do not produce detailed maps. Therefore, selection of the appropriate method for the delineation of WHPA depends on several factors such as perceived level of treatment to groundwater, hydrogeological factors, social factors, level of community involvement, economic condition, etc.

Distance criteria: Distance from the wellhead is the simplest way to arbitrarily delineate a wellhead protection disregarding the factors that control the groundwater flow.

Drawdown: The WHPA may be defined on the basis of drawdown caused by pumping of the well. The surface area relevant to the cone of depression is called the zone of influence of the pumping well and the influenced surface area could be considered as WHPA.

Time of travel (TOT): This criterion is based on the groundwater flow velocity and critical period of time is specified and designated as the time of travel. The hydraulic conductivity and hydraulic gradient of the aquifer control the velocity of groundwater flow. Once a time of travel and velocity has been specified, extent of the WHPA can be determined.

Flow boundaries: The natural boundaries of groundwater flow can be used to define WHPA and a good judgment is required based on the hydrogeological observation of the site and aquifer tests.

7.1 Wellhead protection methods and data requirement

There are several methods available to delineate the WHPA for the groundwater intakes and the advantages and disadvantages associated with each method are summarized below in Table:7.1

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Table 7.1: Available delineation methods for WHPA.

Concept/equation	Data requirement	Advantages(Adv) and Disadvantages (Dis-adv)
Arbitrary fixed radius method		
Arbitrary radius	Reasonable radius	**Adv:** Easy, simple, little time required, minimum data, little technical knowledge. **Dis-adv:** Least accurate, general, challenging concept, level of protection cannot be evaluated.
Calculated fixed radius.		
Radius is calculated by simple equation(Figure :7.1 and 7.2).	Pumping rate(Q), porosity of aquifer(n), open interval of well(H), travel time to well(t)	**Adv:**Accurate than arbitrary radius method, easy, little time required, minimum data, little technical knowledge. **Dis-adv:**Inaccurate for fractured and unconfined aquifer.
Vulnerability mapping		
Vulnerability mapping for groundwater contamination and susceptible area can be delineated as WHPA	Soil map, geology map, hydrogeology map, groundwater level map, structural map, hydrogeological knowledge.	**Adv:**Not required aquifer parameters, use surface features, variety of data. **Dis-adv:**Does not delineate zone of contribution, results are subjective.
Flow system mapping		
Water table map use to delineate zone of contribution for the pumping well(Figure:7.3)	Water level map and hydrogeological knowledge	**Adv:**More accurate,simple,sufficient data is needed. **Dis-adv:** Assumed uniform aquifer, hydrogeological mapping needed, error for large area and flat areas. Issues for confined aquifers.

Flow system mapping with TOT calculation		
Velocity and time of travel are used to calculate the zone of contribution(ZOC) for pumping well.	Water level map, estimated hydraulic conductivity and porosity of aquifer	**Adv:**WHPA from TOT is small than WHPA from flow system boundaries. **Dis-adv:**More errors in estimation of porosity and hydraulic conductivity. Assuming uniform conditions, lot of uncertainty for fractured terrains.
Flow system mapping with uniform flow equation		
Use of flow equation with water level map to define zone of contribution for pumping well(Figure:7.4)	Water level map, estimated hydraulic conductivity(K), porosity of aquifer(n), pumping rate(Q), aquifer thickness(b), and hydraulic gradient(i).	**Adv:**Simple, account effect of pumping on the zone of contribution, data derived from water level map. **Dis-adv:** Assuming uniform conditions ignores the effect of hydraulic boundaries, heterogeneity, non-uniform recharge, errors in estimating porosity and hydraulic conductivity, lot of uncertainty for fractured terrains.
Residence time approach		
Isotopes and geochemistry are used to estimate the TOT and zone of contribution.	Isotope and geochemistry results, knowledge of geochemistry	**Adv:**Can be used for comparison with other methods, does not required aquifer parameters. **Dis-adv:** Knowledge of geochemistry and isotope is required, sometime results are ambiguous, not produce zone of contribution.
Numerical flow model		
3-D groundwater flow model uses to predict the zone of contribution and to simulate the contaminant flow paths.	Knowledge of hydrogeology, aquifer geometry, storage, hydraulic conductivities, recharge, modeling experiences.	**Adv:**Accurate method for delineating zone of contribution, easy to determine groundwater flow path and TOT, availability of software. **Dis-adv:** Needs large amount of data for proper calibration, validation, and calibration. Expensive and need expertise.

7.2 Best practices for wellhead protection.

Other than WHPA, keeping a minimum distance between well and toilet, good practices for construction of wells, toilets with septic tanks/soakage pits, and landfills, control of agrochemicals, etc. are needed to initiate controlling the contamination to water supply intake and aquifer. Some examples are given below;

Example 1: Sealing of interface between rock and overburden, sanitary sealing for immediate surroundings of the borehole, keeping at least a 15 m safe distance to the toilets with septic tanks/soakage pits (Padmasiri, J.P, 1992), and use of blank casing for overburden in hard rock terrain is good practice during borehole construction.

Example 2: When the bottom of toilets with septic tanks/soakage pits are above groundwater level, seal types of septic tanks/soakage pits with ventilated facilities, keeping a minimum of 15 m distance to the toilets with septic tanks/soakage pits is a good practice during toilet construction.

Example 3: Providing an impermeable liner to the bottom of landfill with a leachate collection mechanism and controlling of infiltration of rainwater into landfill are good practices during construction.

Example 4: Application of fertilizers based on the soil nutrients and controlling the water supply to the agricultural field are good practices.

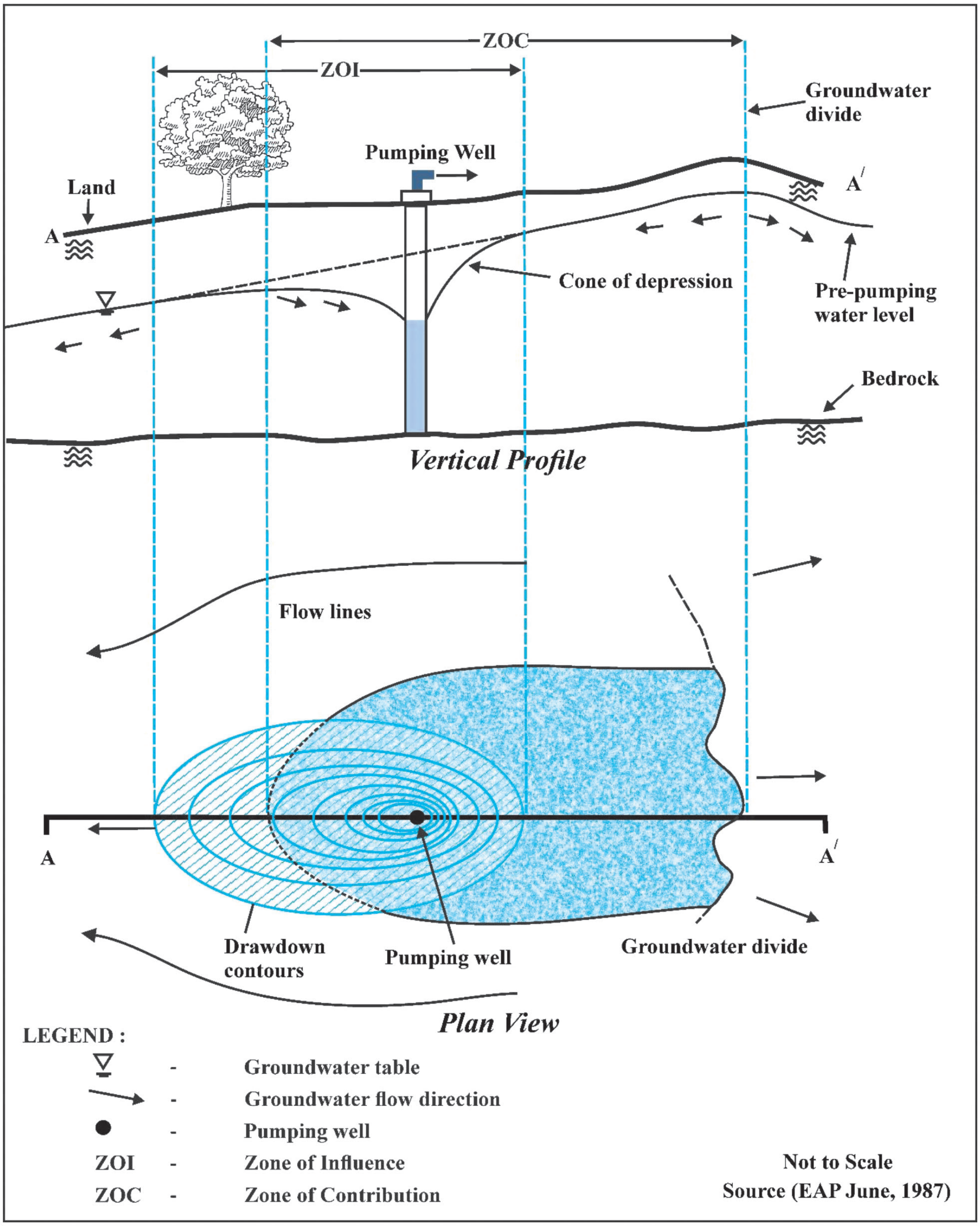
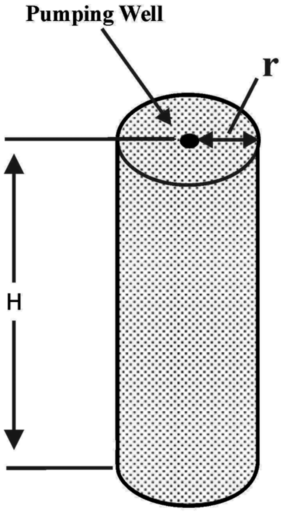


Figure 7.1: Expected zone of influence and zone of contribution in the pumping well in homogenous unconfined aquifer.



$$Qt = n \pi Hr^2$$

Where,

Q = Pumping rate of well
n = Aquifer porosity
H = Open interval or length of well screen
t = Travel time to well (5 years)
r = Radius of well
π = 3.14

Not to Scale

Source (EAP June, 1987)

Figure 7.2: WHPA Delineation of the pumping well by using Volumetric Flow Equation (Calculated fixed radius)

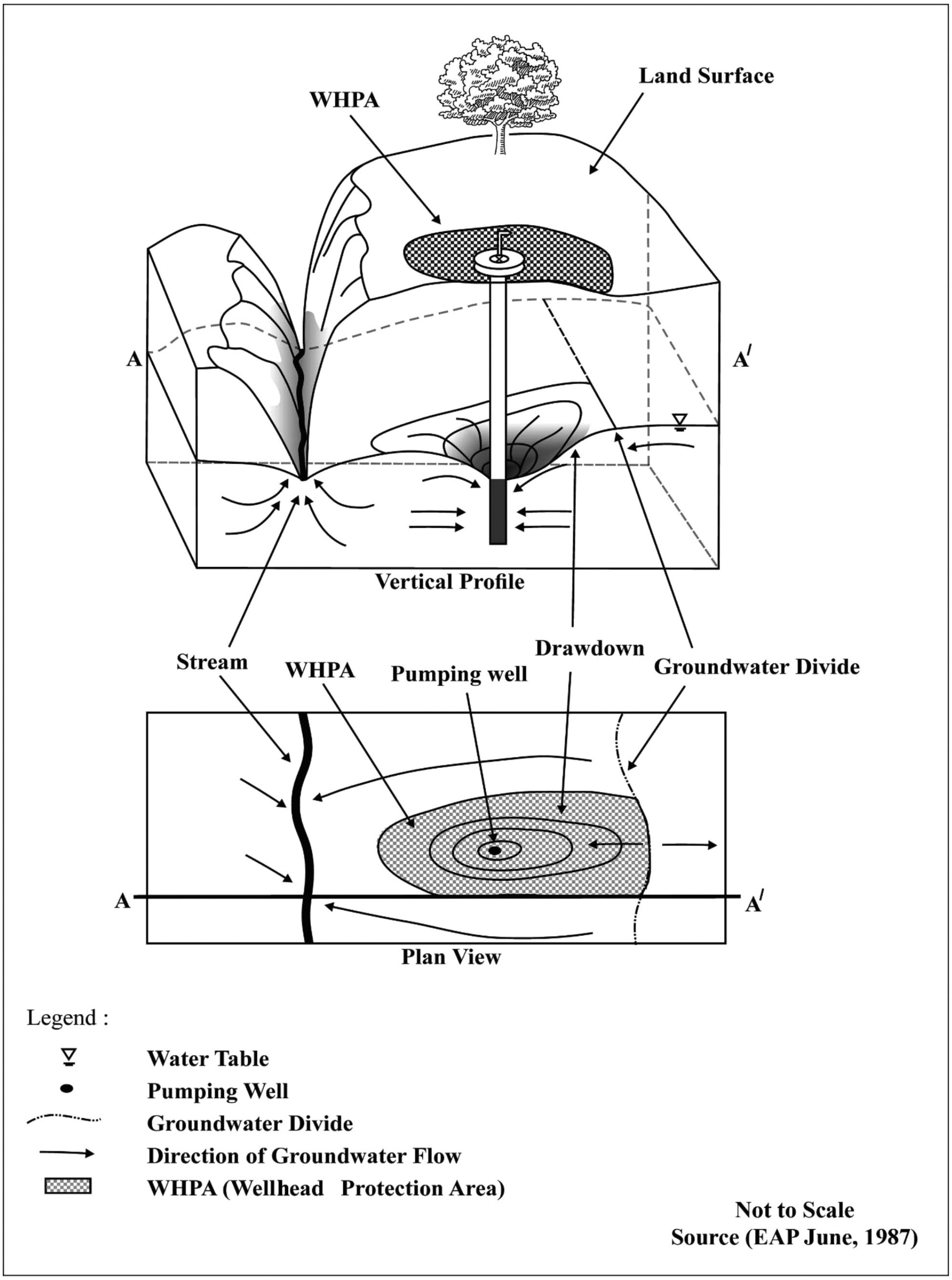
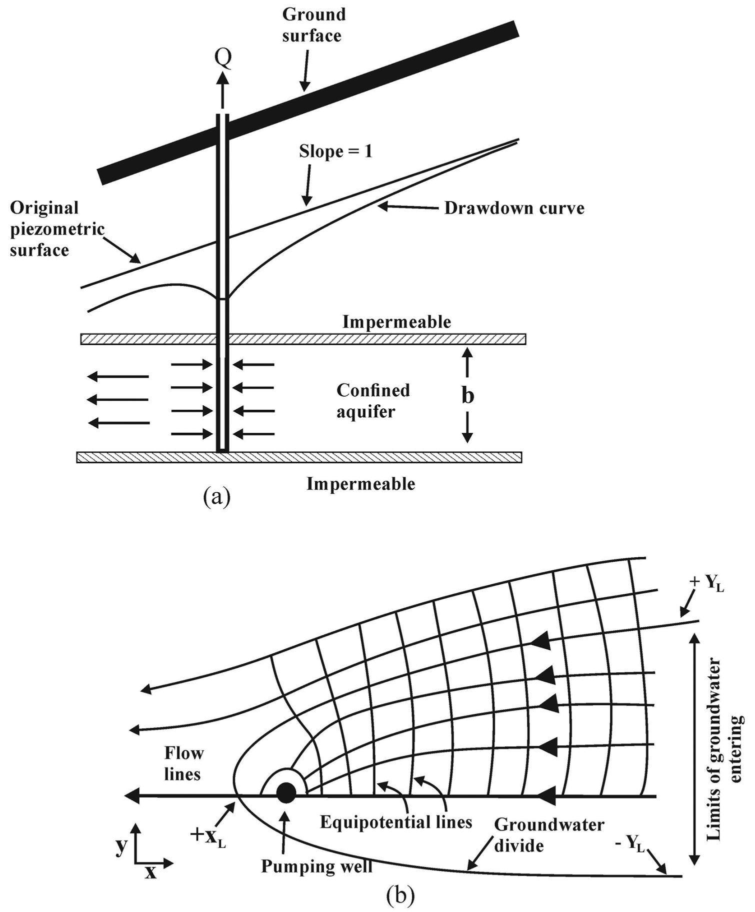


Figure 7.3: Use of groundwater level map for delineating of WHPA of the pumping well.



Uniform - flow equation $\quad -\dfrac{Y}{X} = \tan\left(\dfrac{2\pi Kbi}{Q} Y\right)$

Distance to down gradient null point $\quad X_L = \dfrac{Q}{2\pi Kbi}$

Boundary limit $\quad Y_L = \dfrac{\pm Q}{2\pi Kbi}$

Where,

Q = Well pumping rate
K = Hydraulic conductivity
b = Saturate thickness
i = Hydraulic gradient
π = 3.14

Not to Scale

Source (EAP June, 1987)

Figure 7.4: WHPA Delineation (ZOC) of the pumping well by using groundwater flow.

Chapter 3

8.0 Monitoring and identification of issues of the groundwater intake wells

The collection and analysis of the following data and information are very important to assess the initial stage of the groundwater intake of PWSS and to predict the possible changes in the intake wells in term of quality and quantity;

- hydrogeological report,
- geology and structural maps,
- water quality and geochemistry,
- recharge and discharge area,
- recharging quantity,
- land use patterns,
- pollution source,
- well construction data (water bearing zones and depth to these zones),
- lithology,
- groundwater flow net,
- pumping test data and reports,
- any information relevant to the subsurface conditions of the pumping well or well field

These data and information are to be collected and established in all PWSS for future reference. If these data are not available, these should be collected during the monitoring phases. In addition, available data shall be converted to information for productive use.

The monitoring of operational data of the groundwater intakes and areas outside the intake are to be done systematically and recommended parameters and monitoring frequencies are given in Table 8.1 below. If pumping is conducted from several wells, information of each well will be more useful.

Table 8.1: The recommended monitoring data to be collected from the intake and surrounding areas.

Required monitoring parameter	Frequency
Groundwater intake	
Groundwater level of pumping wells(Before and after pumping) with respect to mean sea level(MSL)	Daily
Water Production (m3/d)	Daily
Pumping hours per day	Daily
Chemical water quality of intake	Dry and wet period.

Outside the groundwater intake	
Regional groundwater table above mean sea level (MSL)	monthly
Construction of wells by other parties within the recharge zone or zone of contribution	monthly
Total groundwater extraction by other parties within the recharge zone or zone of contribution	monthly
Chemical water quality of zone of recharge or zone of contribution	dry and wet period.
Rainfall	monthly
Availability (water level) of water in streams and tanks	monthly
Change of catchment ecology such as deforestation, etc	quarterly

Also, any observation relevant to reduction or increase of pumping rate and water quality with specific time frame will be more useful. In addition, well and aquifer performance must be checked and the recommendations revisited at the time of well development. Therefore, collection and analysis of monitoring data with additional observations are to be performed to predict the possible changes of the groundwater environment (aquifer drain) and issues in the intake wells (well and wellhead problems).

If the monitoring is neglected, life time of pumping wells will be reduced and additional costs have to be borne for construction of new wells.

9.0 Guideline for management of groundwater sources and implementation of WSSP

The groundwater extraction for PWSS shall be conducted with close monitoring of groundwater parameters in order to give minimum impact to groundwater properties such as groundwater table, groundwater flow direction, and groundwater quality. The issues are becoming worse as a result of neglecting the monitoring as well as giving higher impacts to one of above mentioned groundwater properties.
The early identification of the issues is more useful to develop the least cost remedial measures while the cost will be high when the issues reach the critical stage. The guidance and directions for management of issues are discussed under the prepared guidelines.

Once issues are identified, development of adaptation strategies such as protection of groundwater quality, managing groundwater storage, groundwater withdrawal, and groundwater discharge are vital for the protection of groundwater sources.

WSSP is the tool to be used in PWSS to ensure the proper management of the groundwater sources. The relevant steps (as indicated in the Modules of WSSP) include the;

- identification of potential hazards,
- assess the risks,
- prioritization of risks,
- identification of existing control measures
- assessing the effectiveness of the existing control measures and
- re-prioritization of risks,

It is also important now to consider the Climate Resilient aspects of WSSP also in this process, as it is becoming more relevant. The developed Climate Resilient Water Safety and Security Plan(CRWSSP) modules and templates could be used for this purposes.

The WSSP implementation team and external stakeholder should be made aware of these requirements in order to obtain the necessary support to implement the remedial measures.

Guidelines for the management of groundwater sources are given in Annex 2. A typical hazards, risks identification and risk prioritization template is given in Annex 3.

10.0 References.

Guidelines for Delineation of Wellhead Protection Areas: U.S.EPA Office of Ground-Water Protection, Chapters paginated separately, June, 1987.

IGES (2007). Sustainable groundwater management in Asian Cities. A final report of research on sustainable water management policy, Institute for Global Environment Strategies, Japan.

ISO 14686, Hydrometric Determinations-Pumping tests for water wells-Considerations and guidelines for design, performance and use. 2003(first edition).

Padmasiri, J,P,.Jayatilake,G,M. and Koduwegedara, J,P,K,.(1992), Groundwater pollution from Double Pit Latrines, Water Environment and Management, ISBN 0 906055 29 6, Proceedings of the WEDC Conference at Kathmandu, Nepal 30 Aug, 3 Sept.,1992.

Panabokke, C, R. and Perera, A,P,G,R,L,.(2005). Groundwater Resources of Sri Lanka, Report, Water Resource Board, Sri Lanka.

Peter Dillon, Ian Gale, Samuel Contreras, Paul Pavelic, Richard Evans and John Ward, Keynote Paper, IHAS Publication 330, 2009.

www.rwss.lk(Database of Department of National Community Water Supply, updated up to 2020).

Xu, Y. and Braune, E., 1995a. A Guideline for Groundwater Protection for the Community Water Supply and Sanitation Program. Dept. Wat. Aff. & For. 1st ed. ISBN 0-621-16787-8. 1995a.

Annex:1

A summary of the procedure used for pumping test for water wells (BS ISO 14686:2003).

Pumping tests are conducted to obtain data with which to;

- assess the hydraulic behavior of a well and to determine its ability to yield water, predict its performance under different pumping regimes, select the most suitable pump for long-term use.
- determine the hydraulic properties of the aquifer or aquifers yield water to the well, these properties include the transmissivity and related hydraulic conductivities, storage coefficient, and the presence, type and distance of any hydraulic boundaries, and
- determine the effects of pumping upon neighboring wells, watercourses or spring discharges.

A pumping test also provides a good opportunity to obtain information on water quality and its variation with time and perhaps with discharge rate. Before a pumping test is planned, hydrogeological conditions at and around the test site, aquifer response characteristics, groundwater conditions, multi layered aquifers, boundary conditions, and other hydrogeological factors will be assessed. After that, pre-test planning, design of the test, and an equipment test will be done for smooth functioning of the testing program.

The testing methods will be selected based on the well type as below.

Type of intake	Test details
Borehole	Step drawdown test: This test will be conducted with five consecutive steps of different discharging rates in equal incremental basis. The testing period for each step is 60 or 100 minutes. Constant discharge test: Based on the step test, discharging rate for the test will be selected. Testing duration will be selected as per purposes of the testing and minimum testing period for the WSS is about 48 -72 hours. Recovery test: After completion of the pumping phase, this will be done until recovering of more than 90% of drawdown.

Dug well or spring box	Discharge and recovery test: At least two constant rates are selected for the test and pumping will be conducted until the steady stage or pumping water level reaches to bottom of the well. After the pumping, recovery will be measured until recovering of more than 90% of drawdown.

During the testing period, continuous measurement of groundwater level of pumping well and observation wells (MSL), conditions of the surrounding surface bodies, monitoring of discharging rate, etc. will be done as per the relevant ISO standards. These data will be analyzed to obtain the hydrogeological parameters such as transmissivity, hydraulic conductivity, storage coefficient, well loss, aquifer loss, well efficiency, and recommendations for groundwater extraction.

Annex:2

Guideline for the groundwater management system and WSP

	Question	Answer	Event for water quality deterioration, reducing of pumping quantity and specific capacity	Proposed mitigatory measures
1.0 Reduction of pumping quantity and specific capacity of the groundwater intake.				
1.1	Are there any problems in the borehole pump or power system?	yes	1.1a) Poor performance of pump and power system.	1)Repair the pump and power system and confirm the performance
1.2	Seasonal fluctuation in groundwater level and pumping quantity.	yes	1.2a) Fluctuation due to climatic response.	1)It is natural and no measures needed.
1.3	Reduction of specific capacity and it is initial stage.	yes	1.3a) Reduction due to higher extraction than recharge.	1) Re-visit the recommendation by a pumping test.
			1.3b) Reduction not due to well problem (reduction curve is trending downward).	1) Check the pumping schedule with recommendation. If intake is in over pumping stage, give instruction to follow the pumping test recommendation. 2) Check the interference to pumping wells from other users. If yes, inform to WSSP stakeholder Team and regulating authority. Also, See the possibilities to improve recharge. 3) If over pumping and interference from other users are not present, re-visit the recommendation by a pumping test. 4) Develop new groundwater source in the area where there is no interference to pumping wells to meet the water deficit.
			1.3c) Reduction due to well problem	1) Check the pumping schedule with recommendation, If Intake is not in over pumping stage, reduction is due to well problem or aquifer drain. 2) Develop the well using appropriate method and observe the well performance. 3) If performance is not improved by 80%, re-visit the recommendation by a pumping test.

1.4	Reduction quantity of specific capacity is between 20%-50% of the total.	yes	1.4a) Reduction due to aquifer drain	1) Re-visit the recommendation by a pumping test. 2) Develop new groundwater source in the area where there is no interference to pumping wells to meet the water deficit. 3) See the possibilities to improve recharge.
			1.4b) Reduction due to operational issue (over pumping)	1) Check the pumping schedule with recommendation. If intake is in over pumping stage, give instruction to follow the pumping test recommendation. 2) If well condition is not reached to initial stage, develop the well using appropriate method and re-visit the recommendation by a pumping test. Also compare the well performance with initial observation. 3) If performance is not improved by 80%, develop new groundwater source in the area where there is no interference to pumping wells to meet the water deficit.
			1.4c) Reduction due to operational issue(scaling or siltation)	1) Develop the well using suitable methods and observed the well performance. 2) If performance are not improved by 80%, develop new groundwater source in the area where there is no interference to pumping wells to meet the water deficit.
			1.4d) Reduction due to other users	1) If yes, inform to WSSP Stakeholder Team and regulating authority. The quick intervention from WSSP Stakeholder Team and regulator is important. 2) Develop new groundwater source in the area where there is no interference to pumping wells to meet the water deficit until receiving the solution from regulating authority. 3) Also, see the possibilities to improve recharge
			1.4e) Reduction due to man-made activities (surface water diversion)	1) See the possibilities to improve recharge and implement the program for groundwater recharging together with WSSP Stakeholder Team.
1.5	Reduction quantity of specific capacity is more than50% of the total.		1.5a) Reduction due to aquifer drain	1) Develop the wells and observe the well performance. 2) If performance is not improved, plan and implement groundwater recharging.

			1.5b) Reduction due to operational issue (over pumping)	1) Check the pumping schedule with recommendation. If intake is in over pumping stage, give instructions to follow the pumping test recommendation. 2)If well condition is not reached to initial stage, develop the well using appropriate method and re-visit the recommendation by pumping test. Also compare the well performance with initial observation. 3)If performance is not improved by 80%, abandon the wells and develop new groundwater source in the area to meet the demand.
			1.5c) Reduction due to operational issue (scaling and siltation)	1)Develop the well using suitable methods and observe the well performance. 2) If performance is not improved by 80%, abandon the existing wells and develop new groundwater source in the area to meet the demand. 4) Also, explore the possibilities to improve recharge
			1.5d) Reduction due to other users	1) If yes, inform to WSSP Stakeholder Team and regulating authority. The quick intervention from WSSP Stakeholder Team and regulator is important. 2) Develop new groundwater source in the area where there is no interference to pumping wells to meet the water deficit until receiving the solution from WSSP Stakeholder Team and regulating authority. 3) Also, explore the possibilities to improve recharge together WSSP Stakeholder Team.
			1.5e) Reduction due to man-made activities (surface water diversion)	1) Plan and implement the program for groundwater recharging.
2.0	**Groundwater quality deterioration due to contamination sources**			
2.1	**Contamination from recharge area**			
2.11	Chemical and physical contamination of recharge area	yes	2.11a) Potential threat to water quality.	1) Identification of contaminant sources and various contaminants.

				2) Assessment of contaminant load and significance, 3) Asses behavior of contaminants in soil and groundwater as per hydrogeological conditions. 4) Identify the possibility of contamination to well (flow direction). 5) Selection of appropriate method for WHPA based on hydrogeological conditions and assessment of WHPA. 6) Implementation of WHPA with support of WSSP Stakeholder Team. 7) Establishment of a monitoring mechanism through WSSP.
2.12	Bacteriological contamination of recharge area	yes	2.12a) Potential threat to water quality.	1) Identification of contaminant sources. 2) Behavior of contaminants in soil and groundwater. 4) Identify the possibility of contamination to well (flow direction). 5) Selection of appropriate method for WHPA based on hydrogeological conditions and assessment of WHPA. 6) Implementation of WHPA with support of WSSP Stakeholder Team. 7) Establishment of a monitoring mechanism through WSSP.
2.2	**Contamination in the well and immediate surrounding**			
2.21	**Contamination of shallow dug wells or spring (pumping well)**			
2.211	Are there any water quality deterioration in dug well or spring box	yes	2.211a) Similar groundwater level in dug well or spring box and surrounding formation.	1) Check the water quality in surrounding dug wells to observe contaminant source and weather they are from surrounding formation. 2) If not, clean the and disinfection the well. 3) If yes, identify the contaminant source, load level, and risk. 3) If risk is high, decommission the well and propose mitigatory measures to isolate the contaminant source together with the WSSP Stakeholder Team. Also, find new water sources. 4) If the risk is low, propose the mitigatory measures to isolate the contaminant source and monitor the water quality regularly.

				5) If water quality is improving with time, clear and disinfect the well. 6) If water quality is not improving, decommission the well.
			2.211b) Groundwater level is less than 2 m from ground level	1) If aquifer is under confined nature, locate the recharge area and protect as per the WHPA methods. 2) Isolate the hydraulic connection between well and outside the well. 3) if aquifer is unconfined nature, conditions are similar to "2.211a" .
			2.211c) Presence of confined nature water bearing formation	1) Locate the recharge area and protect as per the WHPA methods. 2) Isolate the hydraulic connection between well and outside the well.
			2.211d) Presence of unconfined nature water bearing formation	The expected conditions are similar to **"**2.211a**".**
			2.211e) Chances of penetrating surface water to well or spring box	1) Improved the sanitary seal around the well to stop the mixing of direct surface water to well. 2) Improve the overland flow condition around the well to avoid the stagnation of surface water. 3) Clean the and disinfection the well. 4) Fencing the 15 m radius surrounding area around the well and allow to enter only authorized persons through the implemented WSSP.
			2.211f) Presence of adequate wellhead around well and spring box	1) Check the variation of seasonal water quality of the well. 2) If significant change is observed during the rainy period, improve the sanitary seal around the well and improve the overland flow condition around the well to avoid the stagnation of surface water. 3) Clean the and disinfect the well.
			2.211g) Presence of un used wells	1) If there are any un used wells, clean wells and check the water quality.

				2) If water quality is acceptable, disinfect the wells and put the well cap to avoid the direct contamination. 3) If water quality is not acceptable, decommission the well to prevent the groundwater pollution.
			2.211h) Presence of weep holes within top part of well structure or spring box	1) Close the weep holes to control the preference path ways to the well. 2) Improve the sanitary seal around the well and improve the overland flow condition around the well.
			2.211i) Presence of pollution sources within vicinity of well or spring box.	1) Check the quality of water and conclude the contamination status. 2) If risk is high, decommission the well and propose mitigatory measures to isolate the contaminant source. Also, find new water sources. 3) If the risk is low, propose the mitigatory measures to remove or isolate the contaminant source. Also, monitor the water quality regularly. 4) If water quality is improving with time, clear and disinfect the well. 5) If water quality is not improving, decommission the well.
			2.211j) Chance of flooding to well or spring box	1) Increase the wellhead height to above the flood level. 2) If well undergoes for flooding, clean the well several time until good results and thereafter disinfect the well.
2.22	**Contamination of deep well(pumping well)**			
2.221	Are there any water quality deterioration in deep well	yes	2.221a) Within acceptable limits	No action, continue monitoring
			2.221b) Similar groundwater level in dug well and deep well.	1) Check the water quality in surrounding dug wells and deep wells to observe the contamination source and verify the contaminants are coming from surrounding formation. 2) If contaminants are coming from shallow formation, sealed the interface between rock and overburden. Do not take water from the overburden and improve the sanitary seal.
			2.221c) Obtaining water from the overburden	1) If overburden water is contaminated, do not take water from the overburden and fractures close to the interface.

				2) Seal the annular space between casing and drilled overburden hole.
			2.221d) Presence of sanitary seal for well and chance of penetrating surface water to well.	1) Improved the sanitary seal around the well to stop the mixing of direct surface water to well. 2) Improve the overland flow condition around the well to avoid the stagnation of surface water. 3) Clean the and disinfection the well.
			2.221e) Presence of confined nature water bearing formation	1) Locate the recharge area and protect as per the WHPA methods together with the WSSP Stakeholder Team. 2) Isolate the hydraulic connection between well and outside the well.
			2.221f) Presence of unconfined nature water bearing formation	1) Check the water quality in surrounding dug wells to observe contaminant source and verify the contaminants are coming from surrounding formation. 2) If not, clean and disinfect the well. 3)If yes, identify the contaminant source, load, level and risks. 3) If risk is high, decommission the well and propose mitigatory measures to isolate the contaminant source together with the WSSP Stakeholder Team. Also, find the new water source. 4) If the risk is low, propose the mitigatory measures to isolate the contaminant source and verify the outcome with natural flushing.
			2.221g) Presence of uncapped wells	1) Develop the well, check the well condition and water quality. 2) If well condition including water quality is acceptable, disinfect well and protect the well for future use. 3) If water quality is not acceptable for any purposes, decommission the well.
			2.221h) Chance of flooding to well or spring box	1) Increase the wellhead above the flood level. 2) If well undergoes for flooding, clean the well several time until good results and thereafter disinfect the well.

			2.221i) Presence of pollution sources within vicinity of well.	1) Check the quality of water and conclude the contamination status. 2) If threat for the contamination is low, remove or isolate the contaminant source completely, together with the WSSP Stakeholder Team. 3) If risk is high, decommission the well and propose mitigatory measures to isolate the contaminants source. Also, find the new water sources.
3.0	**Groundwater quality deterioration due to the changing of groundwater environment**			
3.1	Groundwater quality deterioration beyond allowable limits	yes	3.1a) Groundwater quality deterioration due to climatic changes.	1) Reduce the impact to groundwater level by controlling the pumping rate and observe the performance. 2) If it is not improved, promote the groundwater recharging activities together with the WSSP Stakeholder Team. 3) If no improvement is observed, mitigatory measures other than treatment could not be possible.
			3.1b Groundwater quality deterioration due to operational matters and exploitation of earth resources.	1) Identify the geochemical process, enrichment potential, and chemical and bio chemical constituents. 2) Reduce the impact to water level by controlling the pumping rate and connecting additional wells to the system. Also, observe the performance. 3) If no improvement is observed, establish the well development plan.
			3.1c) Groundwater quality deterioration due to weathering and natural mixing.	1) Mitigatory measures other than water treatment could not be possible.

Annex:3

Typical hazards, risks identification and risk prioritization template for groundwater Sources.

No.	Hazardous event	Does a risk exist?		What is the existing control measure?	Is the existing control measure effectively functioning?	Risk level (Green /Yellow /Red)
		Yes	No			
W 1	Are there any potholes that collect polluted water in the surrounds of the well?					
W 2	Is the well protected from animals/ objects entering by a protective wall?					
W 3	Is there a basin or foundation to protect the well from rain or surface water entering in?					
W4	Is the surrounds of the well associated with recreational activities?					
W5	Are there any petrol/diesel usage facilities near the well?					
W6	Is there any chemical fertilizer (or pesticides or weedicides) usage facility within 100 m distance from the well?.					
W7	Is there a cemetery within 200m from the well?					
W8	Is there an abandoned waste dumping sites within 100 m from well?					
W9	Is there an abandoned service station within 100 m from well?					
W10	Is the surrounding area of the well affected by floods, soil erosion and landslides?					
W11	Is there a presence of a source of pollution such as toilets, septic tanks, livestock farming or development facilities within 30 m distance from the well?					

No.	Hazardous event	Does a risk exist?		What is the existing control measure?	Is the existing control measure effectively functioning?	Risk level (Green /Yellow /Red)
		Yes	No			
W12	Is there any deforestation happening in the catchment area of the well?					
W13	Can the well get inundated during a flood situation?					
W14	Is the well, sealed to avoid entry of animals, insects or any external sources of pollution?					
W15	Is the area protected with a fence?					
W16	Is there any bad taste/smell or color in the water?					
W17	Has the well got a proper aeration arrangement?					
W18	Please specify if any additional events					

High and significant(Red): Actions need to be taken to minimize the risk. Proposed actions should be documented in the improvement plan and implemented based on priority and with available resources.

Medium(Yellow): Currently no impact on drinking water safety, but requires attention in operation and/or possible improvement in the medium and long term to continue minimizing risk.

Low or insignificant: Actions may be taken but not a priority, or no action is needed at this time. The risk shall be revisited in the future as part of WSP review process.

Glossary of Terminology

Aquifer	Subsurface geological formation which has structures or textures that hold exploitable groundwater or permit appreciable water movement through them. Horizontal flow is dominant than vertical flow.
Aquifer loss	Head loss at a pumped or overflowing well associated with groundwater flow through the aquifer to the well face.
Aquifer system	A heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding hydraulic unit of regional extent.
Aquifer test	Aquifer testing involves the withdrawal of measured quantities of water from or the addition of water to, a borehole(s); and the measurement of resulting changes in head in the aquifer both during and after the period of abstraction or addition.
Artificial recharge	Process of enhancement of natural groundwater by using man-made conveyances such as infiltration basins or injection wells
Borehole	A constructed hole(relatively small diameter) in the ground from which groundwater can be abstracted, recharged or monitored.
Cone of depression	The depression of hydraulic head around a pumping borehole caused by the withdrawal of water.
Confined aquifer	A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.
Deep borehole	A constructed hole(relatively small diameter) in the rock formation from which groundwater can be abstracted, recharged or monitored
Discharge area	That portion of catchment in which the net flow of subsurface water is directed toward the water table.
Drawdown	The distance between the static water level and the surface of the cone of depression.
Dug well	A dug well is a shallow large diameter man-made pit or hole, from which groundwater can be abstracted, recharged, and monitored.
Ecology	The study of the interrelationships between organisms and their environment.

Fractured zone	A zone of fissures, fractures, cracks, joints and faults within rocks.
Groundwater	Water found in the subsurface in the saturated zone below the groundwater table.
Groundwater level/table	Upper surface of the zone of saturation
Hydraulic conductivity	Measure of the ease with which water will pass through the earth's material; defined as the rate of flow through a cross-section of one square meter under a unit hydraulic gradient at right angles to the direction of flow (m/d).
Hydraulic gradient	This equals the slope of the water table in unconfined aquifer, and the slope of the piezometric surface in confined aquifers.
Natural Recharge	The addition of water to the saturated zone, either by the downward percolation of precipitation or surface water and/or the lateral migration of groundwater from adjacent aquifers.
Porosity	Porosity is the ratio of the volume of void space to the total volume of the rock or earth material
Pumping capacity	Flow rate through a pump at its designed conditions.
Pumping test	Combination of well test and aquifer test.
Recharge area/ zone	An area over which recharge occurs.
Sanitary seal	A paste(grout cement or clay) which protects the well from surface water contamination and provides protection for the upper part of the well.
Shallow borehole	A constructed hole(relatively small diameter) in the overburden from which groundwater can be abstracted, recharged or monitored
Specific capacity	The rate of discharge from a borehole per unit of drawdown, usually expressed as m3/d•m.
Spring	Groundwater flowing naturally at the surface either at a point or over a seepage area
Spring box	Protective structure constructed around the spring to isolate the spring against contamination
Storage coefficient	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Transmissivity	Transmissivity is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is expressed as the product of the average hydraulic conductivity and thickness of the saturated portion of an aquifer
Unconfined aquifer	An aquifer where the water table is the upper boundary and with no confining layer between the water table and the ground surface. The water table is free to fluctuate up and down.
Vulnerability of groundwater	The vulnerability of groundwater to contaminants generated by human activities taking into account the inherent geological, hydrological, hydrogeological characteristics of an aquifer.
Vulnerability mapping	Representing the spatial variability of vulnerability.
Well decommissioning	The sealing and permanent closure of an inactive, abandoned, or unusable water well.
Well development	Physical and chemical treatment of a well to achieve minimum resistance to movement of water between well and aquifer.
Well field	A group or cluster of boreholes in an area used collectively to supply sufficient groundwater to a user or users
Wellhead Protection Area (WHPA)	A surface and subsurface land area regulated to prevent contamination of a well or well-field supplying a public water system
Well loss	Head loss resulting from flow of groundwater the well face into well.
Well test	Well testing is the process whereby a borehole is subjected to pumping under controlled test conditions in order to determine the performance characteristics of a borehole