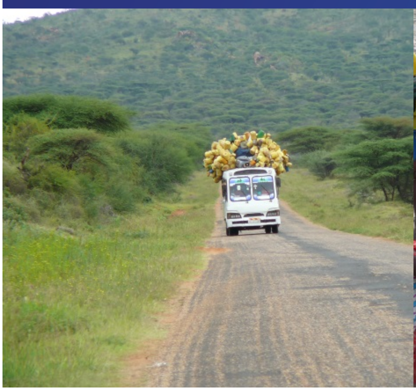
Mar 14, 2022

Mitigation Hydrogeological mapping for Climate Resilient WASH in Ethiopia – LOT 1

Risk Mitigation Strategy

Draft Report Phase 3- BDA/ICB/GW01/2021



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1 Introduction

Risk Mitigation Strategy (RMS) will primarily focus on the steps and processes required to evaluate and mitigate risks to borehole functionality. This will entail assessing current and future risk levels/probabilities and developing mitigation strategies to reduce risk. Step 1 of the process will be to develop a ranking matrix and an analysis/probability of current risk levels for each woreda. Step 2 will entail the development of risk mitigation strategies for various levels/probabilities of risk that relate to: (a) resource potential; (b) water quality; and (c) borehole or source functionality.

The main RMS focus is to outline strategies to make boreholes/water sources climate resilient. As a starting point the following "Mapping Products" can be used to develop cross-cutting strategies:

1. Precipitation map
2. Recharge map
3. Aquifer systems map
4. Topographic maps, versions updated with DEM and/or LIDAR data
5. Lineaments/siting overlay mapping

The major technical areas associated with the provision of sustainable long-term groundwater supply sources include: (a) borehole yield (initial tested yield and borehole-yield maintenance over time); (b) borehole water quality (natural and anthropogenic); and (c) borehole operational functionality.

Borehole yield is the parameter which is directly linked to and can be most affected by climate change. Resiliency, with respect to climate, is based on the strengths and vulnerabilities of the groundwater systems (aquifers) under current conditions. If these conditions can be assessed, this analysis can lead to an evaluation of the degree of risk associated with the groundwater resource, its' sensitivities to climate changes, and strategies for climate-risk mitigation. With this in mind, the focus of the effort will be to outline a methodology and approach to make boreholes "climate resilient." The Lot 1 woreda location map is provided on Figure 1.

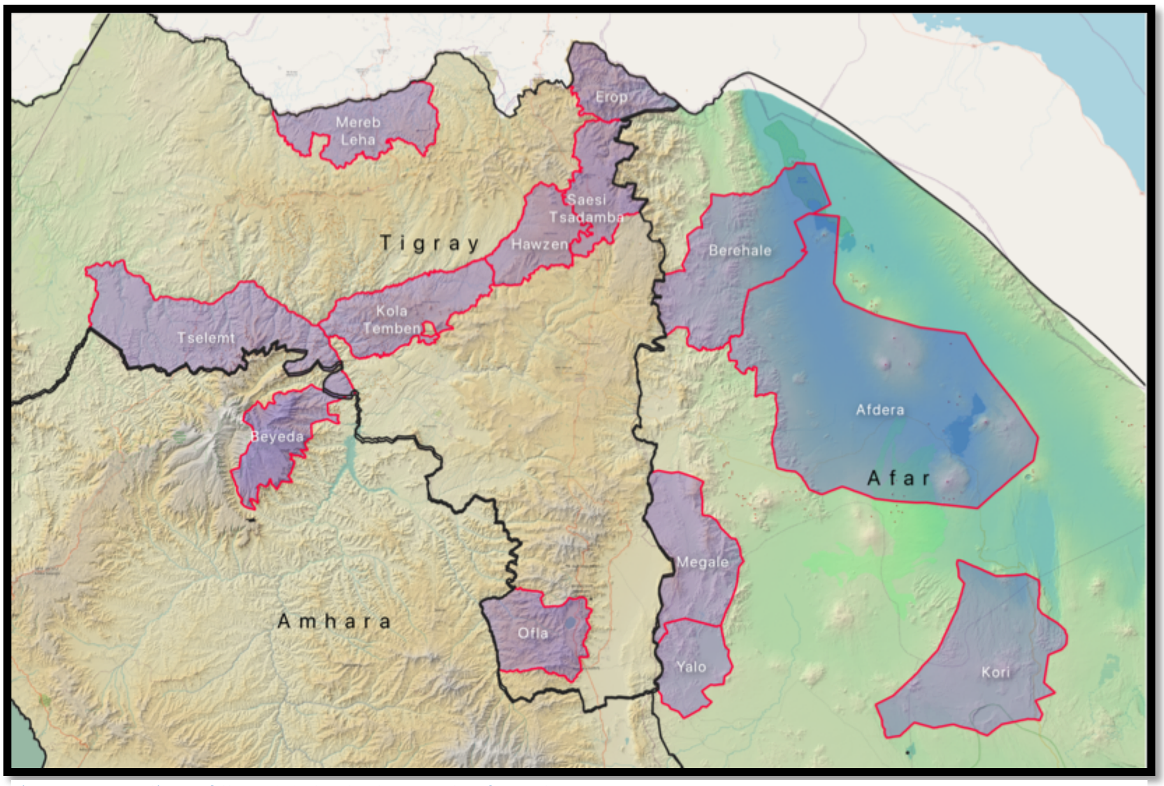

Figure 1 Location of the 13 Selected Woredas for Lot 1

Related questions to be directly considered in the identification and qualification of risk factors for a specific woreda include:

1. Are there concerns with low borehole yields, declining yields, boreholes going dry?
2. Are there concerns with over-pumping of groundwater?
3. Are there concerns with limited freshwater areas?
4. Are there concerns with present or future competing water uses?
5. Have ecological water needs in the area been identified and accounted for in the water balance analysis?

2 Groundwater Risk Analysis

2.1 Introduction

The focus of this initial effort will be to outline a methodology and approach to make boreholes “climate resilient.” To this end, Step 1 entails the development of a ranking matrix to synthesize the baseline risk factors including:

1. Aquifer Type: Productive to Marginal (unconfined/confined)
2. Aquifer Static Reserve: High to Low
3. Groundwater Recharge: High to Negligible (or nil)
4. Current/Future Groundwater Use Comparison to Groundwater Recharge (Analysis of Inputs vs. Outputs).
5. Borehole/Groundwater Vulnerability to Contamination.

A ranking matrix (Table 1) will provide an initial analysis of low to high-risk woredas and differentiate approaches to risk mitigation. The following is a matrix framework, which can be filled out in specific detail to evaluate individual woredas and locations of interest.

Table 1. Risk ranking matrix framework

	Category	Low Risk	Medium Risk	High Risk
1	Aquifer Type -Productive to Marginal	B1/2	B4	B5/6
2	Static Reserve -High to Low	B1/2	B4	B5/6
3	Annual Recharge – High to Negligible (or nil)	>150mm/year	50- 150 mm/year	<50 mm/year
4	Inputs (Recharge) vs. Outputs (Abstraction) - Ratio of inputs/outputs	High Ratio – e.g. 5	GW use < or in balance with Recharge	GW use > recharge
5	Borehole Location Vulnerability to Pollution (protection radius in m)	>100m	50 to 100m	<50m

In general, the sediment/alluvium aquifers are more productive (i.e., higher yielding) than the carbonate, sedimentary, basalts and metamorphic rock aquifers, that in turn are more productive than the basement rock and minor aquifers, as shown on the matrix in Table 1. However, the specific conditions in a woreda/locale should be studied for existing and potential borehole yields.

The Main Aquifer Types in Lot 1 can be grouped into four (4) broad categories including:

1. B1/2 – Sediments/Alluvium
2. B4 – Carbonate, Sedimentary, Basalts, and Metamorphic Rocks
3. B5 – Basement Rocks
4. B6 – Minor aquifers – Shale, Gypsum, Ignimbrite, Rhyolite, etc.

5.

Code	Lithology	Infiltration coefficient	Aquifer class	Class description
M12	metamorphic rocks – phyllite and slate - nics rocks - intermediate and basic lavas, slate, agglomerate, rhyolite and ients - black slate, limestone, sandstone, d greywacke	0.08	**B5**	Fissured aquifers, low productive
M19	Medium grade metamorphic rocks – schist - phyllitic schist, metagreywacke and metaconglomerate	0.06	**B5**	Fissured aquifers, low productive
M29	Amphibolite	0.05	**B5**	Fissured aquifers, low productive
M42	Metamorphosed carbonates	0.08	**B4**	Fissured aquifers, moderately productive
M43	Epimetamorphic basement, granite, basic intrusion, Mesozoic cover of Danakil Alps	0.08	**B5**	Fissured aquifers, low productive
M45	Gabbroic intrusive, metagabbro and metapyroxinite	0.06	**B7**	Non-aquifers
Q12	Alluvium	0.17	**B2**	Intergranular aquifers, moderately productive
Q22	Alluvial and lacustrine sediments – clay and sand with gravel, dunes and other aeolian deposits (in Afar)	0.13	**B2**	Intergranular aquifers, moderately productive
Q25	High fluvial terraces - gravel and low cemented sandstone	0.11	**B1**	Intergranular aquifers, highly productive
S12	Sandstone – Adigrat, Amba Aradom, Enticho	0.07	**B4**	Fissured aquifers, moderately productive
S16	Continental conglomerate and sediments of Red Series: conglomerate, sandstone, silt and clay	0.14	**B1**	Intergranular aquifers, highly productive
S25	Limestone – Antalo, Asem, marble, fossiliferous and sand limestone and sediments of Afdera bed: lacustrine limestone and diatomite	0.08	**B4**	Fissured aquifers, moderately productive
S28	Agula Shale	0.08	**B6**	Minor aquifers
S30	Edaga Arbi Glacials/Tillite and Enticho sandstone	0.07	**B6**	Minor aquifers
S37	Tuff	0.11	**B9**	Alternating porous and fissured moderately productive aquifers
S38	Tufite of Hamsho Units	0.06	**B6**	Minor aquifers
S46	Gypsum with rare calcareous intercalation of Zariga formation or White Series	0.17	**B6**	Minor aquifers
S47	Evaporite (halite)	0.18	**B6**	Minor aquifers
S48	Dolomite interbedded with slate of Didikama Formation	0.06	**B4**	Fissured aquifers, moderately productive
S51	Equal to S30	0.07	**B6**	Minor aquifers
V12	Basic pyroclastic of sub aerial origin	0.15	**B2**	Intergranular aquifers, moderately productive
V17	Basalt with minor trachyte and upper pyroclastic	0.13	**B4**	Fissured aquifers, moderately productive
V21	Mekele Dolerite	0.07	**B4**	Fissured aquifers, moderately productive

V44	Ignimbrite	0.10	**B6**	Minor aquifers
V45	Rhyolite and alkaline over saturated trachyte, alkaline and peralkaline rhyolite	0.14	**B6**	Minor aquifers
V46	Trachyte and phonolite - Adwa Plugs	0.08	**B7**	Non-aquifers
V52	Intermediate and silicic lavas of Afera volcano	0.16	**B6**	Minor aquifers
Vh13	Granite / syenite	0.07	**B5**	Fissured aquifers, low productive
Vh25	Granite / syenite	0.08	**B5**	Fissured aquifers, low productive

2.2 Groundwater Potential Risk (Vulnerability) Identification and Ranking

2.2.1 Aquifer Static Reserve

This analysis will entail an estimate of groundwater held in storage per square kilometer (km2) using the units m3/km2. This storage (static reserve) can be compared to the annual available groundwater recharge (dynamic reserve) to ascertain a "Drought Resiliency Quotient™" (Figure 2). The higher the quotient, the more resilient the groundwater system is to climate fluctuations. The amount of groundwater held in storage can also be compared to the annual water supply demand to evaluate the magnitude of drought buffer inherent in the respective aquifer systems.

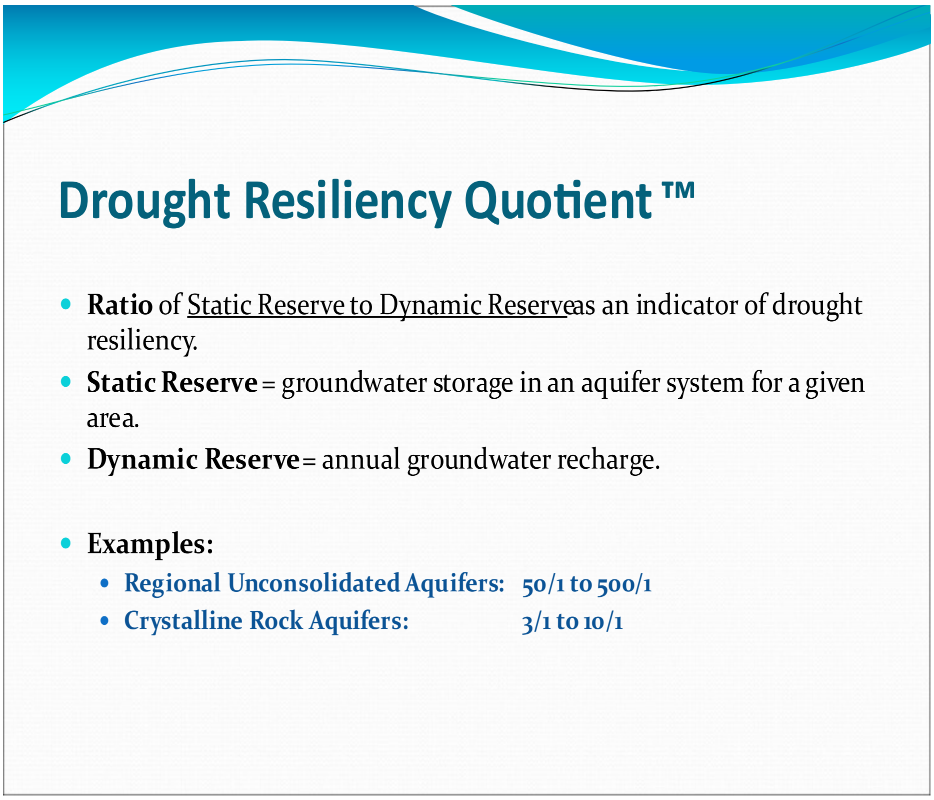

Figure 2. Drought resilience quotient

2.2.2 Annual Recharge (Dynamica Reserve)

The analysis will be derived from the Phase 2 work for Lot 1 and will provide estimates of annual recharge in mm/year during years of normal and drought precipitation. Annual recharge in the <50mm/year range will be considered as low and with a corresponding high degree of risk in terms of aquifer replenishment. Medium risk will be assigned for recharge rates in the >50 and <150mm/year, with a lower level of risk assigned to areas where groundwater recharge is >150mm/year.

Recharge rates are typically derived for shallow or the uppermost aquifer system. If deeper confined or semi-confined aquifer units are under consideration for development, then it will be necessary to modify shallow groundwater recharge estimates to reflect recharge or leakage to deeper aquifer systems, which is generally considerably lower than unconfined aquifer recharge rates.

2.2.3 Groundwater Balance

A simple accounting excel spreadsheet approach (groundwater balance spreadsheet calculator (GBSS)) can be applied as outlined on Figure 3. This balance will indicate whether the renewable groundwater resource (available groundwater recharge) is in surplus to, balanced with, or in deficit with existing and projected groundwater usage, and the magnitude of the surplus or deficit.

Groundwater Balance Spreadsheet (GBSS) - 2021

Woreda Name:

		Normal	Drought	Units
Area of Woreda		500		km^2
Annual Precipitation		600	400	mm/Yr
Total Groundwater Recharge		12.00	8.00	MCM/Yr
% of Precipitation	4%			
Groundwater Ecological Reserve		2.40	1.60	MCM/Yr
% of Total Groundwater Recharge	20%			
(A) Available Groundwater Recharge	A =	9.60	6.40	MCM/Yr

Groundwater Use for Humans					
Human	Population	150,000		0.8213	MCM/Yr
	Demand	15	LPP/day		
Groundwater Use For Livestock					
Cattle	Population	50,000		0.4928	MCM/Yr
	Demand	27	LPA/day		
Goats	Population	120,000		0.2190	MCM/Yr
	Demand	5	LPA/day		
Camels	Population	50		0.0009	MCM/Yr
	Demand	50	LPA/day		
Horses	Population	100		0.0016	MCM/Yr
	Demand	45	LPA/day		
Sheep	Population	70,000		0.1278	MCM/Yr
	Demand	5	LPA/day		
Donkeys	Population	25,000		0.1460	MCM/Yr
	Demand	16	LPA/day		
Groundwater Use For Commercial/Industrial/Irrigation					
Commercial/Industrial				0.00	MCM/Yr
Irrigation	Area	20	Hectares	1.2614	MCM/Yr
	Demand	2	LPS/ha		

		Normal	Drought	Units
(B) Total Groundwater Use	B =	3.07	3.07	MCM/Yr
(C) Net Available Groundwater	[A-B] = C =	6.53	3.33	MCM/Yr

Notes:
1. MCM/Yr: Million Cubic Meters per Year
2. LPP/day: Liters per person per day
3. LPA/day: Liters per animal per day

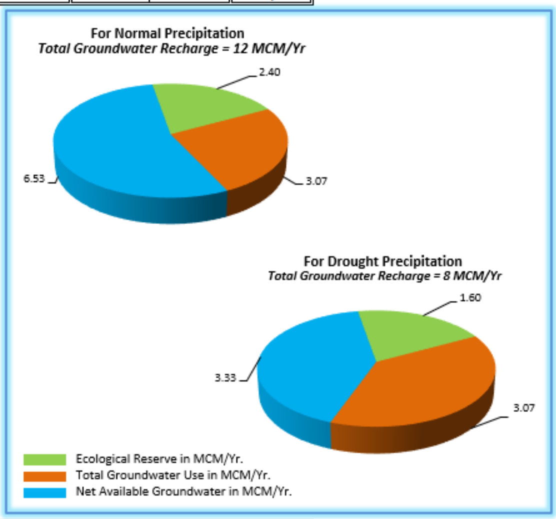

Figure 3. Example Groundwater Balance Spreadsheet (GBSS) Calculator

The Groundwater Balance Spreadsheet (GBSS) calculator provides a format to develop estimates of the surplus or deficit of annual Net Available Groundwater for a small drainage basin or woreda based on annual groundwater recharge estimates and water demand for both normal and drought conditions. The annual surplus or deficit Net Available Groundwater is equal to the annual Available Groundwater Recharge taking into account an ecological reserve (for stream baseflow and wetland maintenance) minus the Total Groundwater Use.

The GBSS is intended as a continuing planning tool and the excel spreadsheet is well suited to adjustment as additional data are realized, as it allows easy changes/refinements to the inputs of supply and demand to reflect current and future conditions and development scenarios.

2.3 Groundwater Quality Risk (Vulnerability) Identification

The principal risks with regard to borehole water quality include:

- Anthropogenic groundwater quality issues, such as bacteriological (E coli, Total Coliform; Fecal Coliform) and elevated Nitrates.
- Natural groundwater quality issues, such as elevated Total Dissolved Solids (TDS), Fluoride, and Arsenic.
- Nearby land uses that might impact groundwater quality.
- Releases, spills or leaks, such as of petroleum substances powering the borehole pump.

Anthropogenic Sources: To assess groundwater quality risk at individual borehole locations, a site-specific survey and contaminant source identification survey is required for anthropogenic sources, e.g. latrines, septic systems, petroleum product storage/distribution locales, agricultural product storage locales for pesticides and fertilizers, site drainage conditions (run-on and runoff). This will entail development of site maps showing distances to respective existing and potential future sources of groundwater contamination.
Natural Groundwater Quality: Issues should be identified from available water-quality information and data from proximate existing boreholes, and recent sampling and analysis of water samples from project boreholes.

2.4 Risks Related to User and Source Type

Water source type risks relate to borehole depth, yield, and functionality. These include:

- Some examples of operational risks include:
    - Borehole/pumping system malfunctions or breakdowns
    - Availability of power for pumping, i.e. fuel or electricity
- Risk of damage due to location, poor security, and theft.

3 Risk mitigation strategies

Based on the development of risk levels in Step 1, "Risk Mitigation Strategies" can be developed and applied. Preliminary examples of identified risks and mitigation strategies are outlined below.

3.1 Risk Mitigation Strategies for Groundwater Resource Potential/Availability

3.1.1 High Existing and Potential Risks

Examples of high risk include:

- Nil to negligible recharge (<50mm/yr.).
- Groundwater use > recharge.
- Pollution sources <50m from a production borehole.

Potential mitigation measures might include:

- Water rationing/use restrictions.
- Brackish water-resource evaluation and treatment.
- Wastewater reuse for certain applications such as irrigation.
- Land-use restrictions within a 50m radius of a production borehole.

3.1.2 Medium Existing and Potential Risks

Examples of medium risk include:

- Annual groundwater recharge in the 50 – 150mm/yr. range.
- Groundwater use and recharge are in balance.
- Static reserve provides a good drought buffer.

Potential mitigation measures might include:

- Water-use restrictions.
- Groundwater recharge enhancement (MAR).
- Local watershed management to enhance groundwater recharge.
- Installation of deeper boreholes in certain aquifer units where fresh groundwater occurrence at depth has been confirmed.

3.1.3 Low Existing Risks

Examples of low risk include:

- Annual groundwater recharge >150mm/yr.
- Productive aquifer systems with large static reserve
- Groundwater recharge significantly > groundwater use
- Groundwater management systems in place and working.

3.2 Risk Mitigation Strategies Related to Water Quality

Risk mitigation strategies related to water quality include:

- Borehole siting that takes into account nearby land use and establishing protective distances to potential groundwater contamination sources.
- Wellhead drainage works, land use controls, and housekeeping in protection zones around production boreholes.
- Proper borehole construction with sanitary protection against artificial pathways for contaminant migration, e.g. casing annulus infiltration, by installing a protective column of cement grout (15m minimum) in the borehole-casing annulus.
- Fuel storage and spill control plans for fuel storage systems.
- Developing wellhead protection programs with fixed radius protection zones for various contaminant types. The most restrictive zone is typically for bacteriological related contaminant sources (latrines and septic drain fields).

3.3 Risk Mitigation Strategies for Source Functionality

Key Risk Mitigation Measures (RMM) that can be applied to maximize borehole yields and make them sustainable in the long term and through wet and extended dry periods are outlined below.

3.3.1 Siting Strategies

Borehole siting strategies include:

- Borehole siting in areas where focused recharge takes place such as fractured areas in the basement rock and volcanic areas.
- The application of technical tools such as remote sensing and ground geophysical surveys to optimize drilling locations.

3.3.2 Optimizing Borehole Designs and Depths

Borehole depths should be optimized to account for water-level fluctuations – seasonal, long term, and induced by climate change. Optimal borehole designs can be achieved by:

- Developing detailed borehole drilling and construction specifications for the drilling contractor and professional drilling/construction oversight.
- Use of materials (casings, borehole screens, filter packs, grout) that meet applicable standards.
- Scientifically designing borehole screen slot-size openings and filter pack sizing to prevent sand pumping.
- Borehole casing and screen material designs taking into consideration corrosion and incrustation potential based on the corrosivity, TDS levels in the groundwater.
- Adjusting borehole construction materials as appropriate. For example, the use of PVC and stainless-steel well casing and screens in corrosive and high TDS environments. PVC casings have depth and temperature limitations. Casing annulus sealing materials (cement grout and bentonite) may have to be adjusted depending on the TDS and sulphate concentrations in groundwater.

3.3.3 Sustained Yield Analysis

Professional analysis of constant-rate pumping tests should be conducted to determine long-term sustained borehole yields for both current and future populations and taking into account climate change impacts.

3.3.4 Contracting and Training Procedures

A focus should be placed on:

- Contracting professional firms for borehole and pumping system construction.
- Training borehole operators by means of on-the-job training and workshops.
- Instituting formal O&M procedures.

3.3.5 Developing Wellhead Protection Programs

Wellhead Protection Programs should be developed using a tiered approach:

- Tier 1 (within <50m radius from a borehole):
  - Security fencing.
  - Daily Wellhead Inspection.
  - Housekeeping.
  - Avoiding unauthorized system intrusions.

- Tier 2 (50 to 100m radius of the borehole):
  - Review and input to proposed land-use changes.
  - Creation and operation of water reserves or conservation districts
  - Emergency response to spills, releases or leaks.
  - Education of the community regarding wellhead protection

- Tier 3 (>150m radius)
  - As above for Tier 2

3.3.6 Operation and Management of Water-Supply Boreholes

Training for water system operators should include the following:

- Key data collection
- Data analysis applications
- O&M daily checklists
- Repair vendors – type etc., and
- Chain of command

System monitoring is critical for the smooth operation of the borehole and pumping systems, including identification of types/points/causes of decline or failure, and timely mitigation intervention and troubleshooting. The types of data which should be collected include:

Condition of equipment via routine inspection

- Daily pumpage (rate (Q), duration, volume)

- Water levels (static and pumping)
- Water level drawdown (s) to evaluate decline in specific capacity (Q/s)
- Water quality (E. coli – monthly, color, odor, turbidity, air bubbles)
- Rainfall

Indicators of need for borehole operation modification and remedial action include:

- Decline in pumping/static levels
- Decrease in borehole pressure
- Cascading (air entrainment)
- Sand pumping/turbidity
- Reduction in borehole yield and specific capacity (Q/s)
- Color, odor, turbidity changes in the pumped discharge

A formal plan should be established to specify the parameters and frequency of data collection and analysis.

4 Lessons Learned from Other Countries

4.1 Groundwater Source Sustainability

Regulations in some states in the US require that cumulative groundwater withdrawals in a basin or regional aquifer system do not exceed natural groundwater recharge or dynamic reserve as noted in this paper. Certain river basins and locales also focus on groundwater withdrawals not impacting stream/river baseflow (aka dry weather flow). In the State of New Jersey, the policy is that groundwater withdrawals should be no greater than 20% of natural groundwater recharge, and water allocation is controlled by the state on this basis.

4.2 Water Quality Protection

The initial element in source water quality protection begins during the siting periods when present and future expected land uses are mapped and inspected within a certain radius from proposed well sites. Separation distances from contamination sources such as septic tanks; latrines; contaminated drainageways; fuel and pesticide storage areas etc. are developed and enforced.

4.3 Wellhead Protection Programs

In many countries and locales, wellhead protection programs and planning have been implemented to manage and regulate land uses around a production borehole wellhead. Wellhead protection zones are typically tiered with the Tier I Zone being the most restrictive in terms of allowable and prohibited land uses. The Tier II and III Zones typically are less restrictive. The protection zones are defined by travel times from areas within a borehole's capture zone to the wellhead.

4.4 Borehole/Wellfield Functionality

The successful operation of a groundwater based water utility requires the adoption and implementation of a set of "Standard Operating Procedures" or SOPs. These would take the form of:

- Key data collection such as static and dynamic pumping levels; pumping rates and durations on a daily basis.
- Data analysis applications such as water level; well efficiency, and water quality trends.
- Development of daily O&M checklists.
- Emergency contacts and reliable vendors.
- Water quality sampling parameters; sampling locations and frequency.

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