

Water Safety Plan (WSP)

A Risk Based Approach for Water Safety



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Preface

Ensuring access to safe drinking water is globally acknowledged as an effective means of promoting good health and reducing poverty. Accordingly, the WHO guidelines for Drinking Water Quality (2004) recommended implementation of Water Safety Plans (WSPs) as a cost-effective, management-oriented, preventive approach to drinking water safety.

AusAid, under WHO-AusAid partnership for water quality management has set in motion its Water Safety Plan Programme since 2005. The completed Phases 1 and 2 of the programme has been instrumental in initiating capacity building in support of WSPs in a number of countries, including Bangladesh. Building on the achievements of Phases 1 and 2, the Phase 3 of the Partnership is focusing on mainstreaming WSPs such that they become standard O&M practice for water supply. A key pre-requisite for achieving this objective is a strong knowledge-base of key professionals involved in the water supply sector.

In Bangladesh, the water supply sector is primarily run by the graduates from technical and engineering institutions. Thus, mainstreaming of WSPs in the sector would depend to a large extent on the knowledge and technical know-how of these technical/ engineering graduates. The concept of “Water Safety Plans” is relatively new, and has not been incorporated in the curriculum of technical and engineering educational institutions. At the same time, new lessons have been learnt from the implementation of WSPs in Bangladesh over the past years. Therefore, it is very important to introduce the concept and practice of WSPs in the curriculum of engineering and technical education.

This book on WSP is an outcome of the initiative of WHO-Bangladesh and ITN-BUET in mainstreaming the WSPs in the water supply sector of the country. This book will help develop a strong knowledge-base of undergraduate level technical/engineering students on WSP, and enable them to better prepare themselves in facing the challenges in the water supply sector of the country. It has been developed such that it fits into and supplement, the existing course curricula on water supply and sanitation at different technical/engineering institutions.

The WSP book has been developed through extensive consultation with faculty members currently involved in teaching and research on water supply and sanitation, and the WASH professionals in the field. Sincere acknowledgement to all who contributed in the development of this document.

Abbreviations

AIRP	Arsenic and Iron Removal Plant
BUET	Bangladesh University of Engineering and Technology
DPHE	Department of Public Health Engineering
FC	Faecal Coliform
GI	Galvanized Iron
HDP	High Density Polyethylene
IRP	Iron Removal Plant
ITN	International Training Network
NGO	Non Government Organization
O&M	Operation and Maintenance
PSF	Pond Sand Filter
PVC	Polyvinyl Chloride
SOP	Standard Operating Procedure
WHO	World Health Organization
WSP	Water Safety Plan
WSF	Water Safety Framework

1.0 Background

Although water is abundant in Bangladesh, a majority of population is facing scarcity of safe drinking water due to water pollution (e.g., arsenic contamination of groundwater and microbial contamination of surface water) and seasonal depletion. Moreover, inadequate infrastructure, poor resource management, poor hygiene behavior and unsanitary practices aggravate the water quality problems. Although the groundwater that constitutes the major share of urban and rural water supplies is of good quality in many places, the water that actually reaches to the customer does not remain safe. The success story of hand tubewells in providing safe water to millions of rural Bangladeshis has suffered major setback in recent years. Widespread presence of arsenic in groundwater has affected safe water supply especially in the south, south-western and north eastern regions of the country; bacterial contamination has also been reported in rural water supplies based on shallow tubewells. It is well known that most of the city dwellers in Bangladesh do not get safe water from the supply mains because of recontamination in pipelines and storage tanks; end of the tap treatment through filtering and boiling is common among city dwellers. A study in 100 pourashavas where piped water supply systems were established (Mahmud S.G. and Nuruzzaman M., 2003)¹ revealed that all the production wells in six Pourashavas contained arsenic above the Bangladesh standard of 0.5 mg/l. With regard to iron, 60% of production wells in 55 Pourashavas contained iron above the Bangladesh drinking water standard of 0.3 mg/l and 54% of production wells in 71 Pourashavas contained manganese above the Bangladesh standard of 0.1 mg/l.

The “traditional approach” to water quality and safety management has relied on the testing of drinking water. This takes place as water leaves the water points (e.g., hand tubewell) or treatment works (e.g., IRPs, AIRPs) or at selected points, either within the distribution system or at consumer taps/storage location. This is known as “end point testing”. The problem with this approach is that the results are often “too little” and “too late” for preventive action. “Too little” because so few samples could be collected and tested compared to the amount of water produced. Therefore, conclusions drawn about the safety of water from the results of such sampling are compromised, particularly for microbial quality. More importantly, the “end point testing” does not give clues on the origin/source of the

¹ Mahmud S.G. and Nuruzzaman M. “Arsenic Contamination of Production Wells in Pourashavas in Bangladesh.” Arsenic Contamination: Bangladesh Perspective, ITN Bangladesh, 2003: 63-71.

water quality problem. “Too late” because by the time the results are available (particularly for microbial quality), the water has been already supplied and may have been consumed, and therefore preventive action is no longer possible.

Depending on the type of water supply system, risks to water quality and safety may come from diverse sources. Hand tubewell based water supply systems for individual households are the most widespread and simplest of water supply systems in the country. Microbial risks to tubewell-based water supply system may come from a range of sources/activities including improper well installation and development (e.g., use of cow dung during well boring), leaching of Contaminated water from nearby pit latrines, improper management/usage of tubewell (e.g., faulty/no platform, anal cleansing of children in faulty tubewell platform), as well as improper handling and storage of tubewell water. It is obvious that even for this simple water supply system, ensuring water quality and safety on a continual basis using the “traditional approach” of “end point testing” would be almost impossible. The situation would become much more complex for water supply systems involving treatment and distribution networks (e.g., piped water supply systems). For such systems, the risks to water quality may come from a much wider range of sources and activities. Apart from the characteristics of catchment and water sources (surface water or groundwater), risks to water quality of such systems may come from any treatment processes, intrusion of contaminants through distribution networks (e.g., due to leakage, improper joints/service connections, inadequate pressure or intermittent supply, intervention of consumers e.g., pumping), as well as improper storage (in overhead tanks or in containers) and handling. Ensuring water quality and safety for such a system by “end point testing” is almost impossible.

The most effective means of consistently ensuring the safety of a drinking water supply is through the use of a comprehensive risk based approach that encompasses all steps in the water supply “from catchment to consumer”. The WHO Guidelines for Drinking Water Quality (GDWQ) (WHO, 2008; WHO, 2011) call such risk based approaches Water Safety Plans (WSPs). WSPs represent an evolution from sanitary surveys and vulnerability assessments to cover the whole of a water supply system and its operation.

The WSP approach uses the principles and concepts of risk management, which revolve around three fundamental questions:

1. What are the risks?

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2. How could the risks be controlled? and
3. How well are the risks currently being controlled?

As part of this risk assessment and management process, a WSP also seeks to identify (for the whole system from source to mouth):

- The hazards that the water supply is or could be exposed to, what hazardous events would introduce those hazards into the water supply and what the level of risk is of the hazards being introduced to the water supply;
- How each hazard could be prevented, reduced or managed;
- How the control measures will be monitored;
- What actions are required to restore control if control is lost; and
- How the effectiveness of the WSP can be verified.

The overall objective of WSPs is to ensure water safety, and hence to protect public health. WSPs are system-specific and as complicated or simple as the systems to which they are applied. So a WSP for a household level hand tubewell will be relatively simple whereas a WSP would be much more complex for a piped water supply system in a city involving a treatment plant and distribution network. It is important to recognize that a WSP should continue to be used for as long as a water supply system remains in operation.

In Bangladesh, WSPs were initiated on a pilot basis in rural water supply systems in 2005. Gradually, technology-specific WSPs, monitoring tools and sanitary inspection tools were developed. In 2008, urban water supply systems started implementing WSPs. Prompted by a favorable policy environment and institutional focus, DPHE has, of late, scaled up WSPs in Pourashava and Rural Piped Water Supplies and different point sources with technical assistance from the WHO. Some NGOs are also implementing WSPs in their respective project areas.

2.0 Water Safety through Water Safety Plans

2.1 What is a WSP?

The major activities involved in a WSP can be divided into:

- (a) **System description and hazard analysis:** The objective of system assessment is to determine whether the drinking water supply system (to the point of consumption) is delivering water of acceptable quality, including identification of risks at different stages/steps within the system. This also includes the assessment of design criteria of new systems.
- (b) **Identification and monitoring of control measures:** This involves identification and assessment of control measures to stop/reduce the identified risks and ensure that the water quality targets are achieved. For each control measure identified, an appropriate means of operational monitoring should be defined that will ensure that any deviation from required performance is rapidly detected in a timely manner.
- (c) **On-going management and communication:** These plans describe actions to be taken during normal operation or emergency conditions and document the process, including upgrade and improvement planning, monitoring and reporting plans and supporting programs.

2.2 Developing a WSP

The steps typically followed in developing a WSP vary with the nature of the water supply system (e.g., household point source supply versus city piped water supply) and also vary from country to country. Bangladesh's Water Safety Framework (WSF, GoB, 2011) proposes seven-step WSP, which is more suited to relatively complex water supply systems (e.g., piped water supply systems in pourashavas).

In this document the WSP processes have been simplified to five step processes which are shown in Figure 1. Depending on the nature of the water supply system, these steps can be simplified or elaborated. For example, Step 3: "risk assessment, prioritization and control" may require certain tools (e.g., inspection

forms, check lists, field testing kits) for a more complex water supply system but for a household tubewell the requirements would be much simpler.

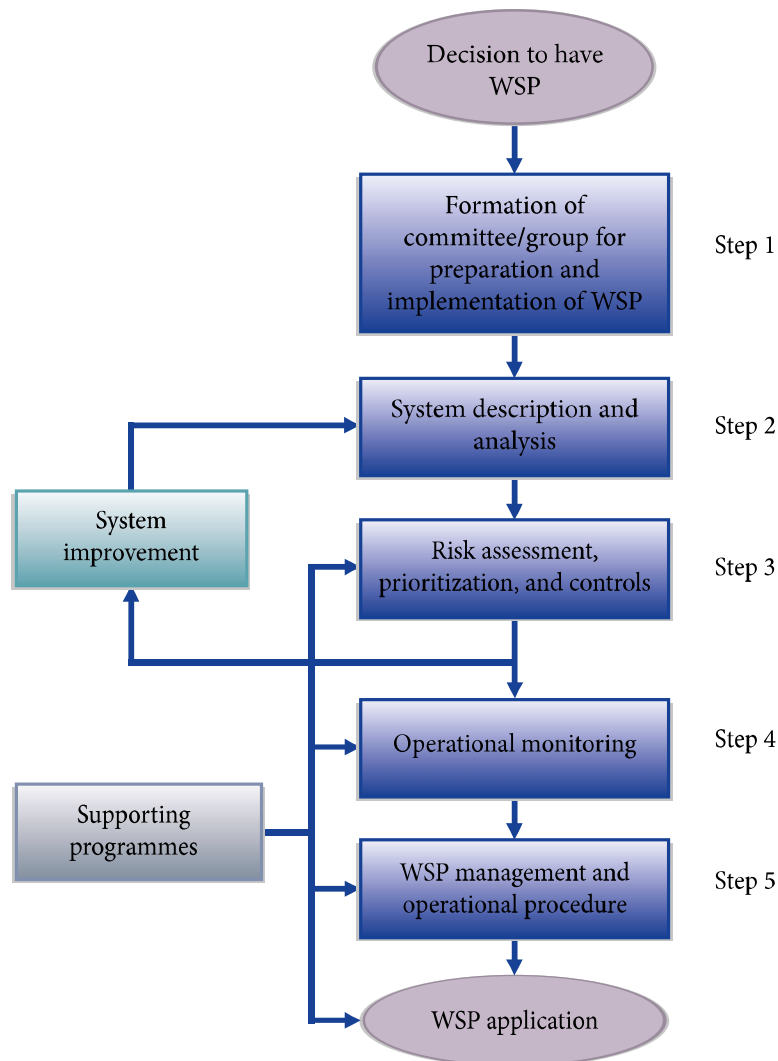


Figure 1: Major steps in developing and implementing a WSP

2.3 WSP Steps

However complex a water supply system may be, there are five key steps in a WSP:

1. Formation of Committee/Group for the preparation and implementation of WSP;
2. System description and analysis;
3. Risk assessment, prioritization and control;
4. Operational monitoring; and
5. WSP management and operational procedure.

These key steps are described below.

Step 1: Formation of Committee/Group to prepare and implement a WSP

For any water supply system, a WSP Committee or Group is required for WSP preparation and implementation. The main role of the Committee/Group is to undertake and/or coordinate the WSP activities. The composition of the Committee/Group would mainly depend on type of water supply system. For example, for a city or pourashava water supply system, a WSP Committee/ Group should comprise members with experience and from multi-disciplinary backgrounds (e.g., water supply, water quality, health) who understand the components of the water supply system and are well placed to assess the risks and identify control measures for each system component. However, for a household tubewell system a WSP Committee would be much simpler – maybe just one family.

Step 2: System description and analysis

A system description should include:

- Description of the system, including a flow diagram;
- Description of quality of the water currently being provided; and
- An identification of the users and uses of the water.

The system description should cover the following major features, as appropriate, for any system being assessed:

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- Source of water and catchment: e.g. capacity of the source in relation to demand, protection measures required and current measures in place, developments in the catchment that may affect quality, known water quality problems.
- Water abstraction/collection: e.g. hand pump tubewell for a household water supply system; deep tubewell for a pourashava; surface water intake for a large urban system.
- Treatment processes applied: information about configurations, treatment processes employed (e.g. coagulation, filtration, chlorination), numbers of units, age of plant, known design faults (if any).
- Storage within the distribution system: how many service reservoirs and their volume, areas that they serve, age, known design problems.
- Distribution system: pipe size, diameter, material, jointing, limit of responsibility of utility, extent, population served, known problems.
- Water storage and handling at consumer level: for instance household level overhead storage tank in an urban area; kolshi/bucket in a rural area.
- Water uses: intended uses of water.
- Water quality: supplied water quality and relevant water quality standards.
- Water supply problems: e.g. shortage, intermittent supply, leakage etc. or suspected change in source water quality.
- Manpower: e.g. trained staff for a Pourashava water supply.

An example of a water supply system description, adopted from the WSP for Chapai Nawabganj Pourashava, is presented in Table 1.

Table 1: Description of water supply system for a Pourashava*

Step	Description
Water source	Water is abstracted through five tubewells (deep tubewell) by pumping. Total pumping time is 10-12 hours per day and is intermittent (6 am to 2 pm; 4 to 7 pm and in Ramadan 7 to 9 am; 2 to 5 am; 2 to 5 pm). Water is fed to the distribution system both directly from pumped wells and from an overhead tank during periods when the pumps are turned off.
Water treatment	Water from only one tubewell (out of the five) and the overhead tank is chlorinated before distribution.
Storage after treatment	Water pressure is maintained during the daytime utilizing 1.5 lakh gallon capacity overhead storage tank. The tank is isolated and filled at night. As a result, the distribution system is not continuously pressurized.
Distribution of water	Water is distributed via a piped network composed of PVC, HDP, or GI pipes. Pipe size range is 100 to 200 mm.
Household collection and storage	Water is supplied to the consumers through house or yard connections and street taps. Floating and poor people collect water from public taps in containers and often transfer water to other containers (e.g. jug) for storage within the household. Many households with house connections have underground reservoirs and/or a rooftop reservoir. People store water to ensure 24 hour supply.
Water uses	The supplied water is intended for domestic uses.
Present water quality status	The area has arsenic affected aquifers. Source water must be tested for arsenic and only arsenic-safe wells should be used. Other important water quality issues concern iron and manganese.
Water supply problems	Intermittent supplies require special consideration (e.g. ingress of contaminants into the distribution system during periods of low or no pressure). Contamination of stored water (particularly in the underground and rooftop reservoirs).
Manpower	The pourashava has limited trained manpower for operation and maintenance of the water supply system.

* Adopted from WSP report prepared for Chapai Nawabganj Pourashava

Flow diagram for system description:

When developing a WSP, the description of the whole water supply system would normally be presented in a flow diagram. A good conceptual flow diagram greatly facilitates subsequent assessment of hazards, risks and controls, as it allows:

- Identification of ways that hazards can affect the system;
- Identification of appropriate control measures.

It is important to capture all the main elements of the water supply system in the flow diagram in sufficient detail to enable accurate assessment of risks and identification of control measures. Reference should be made to maps showing sewage treatment plants and other potential polluters. A flow diagram will be system-specific and different for each water supply system. Example flow diagrams for different types of water supply systems are shown in Figures 2-4. The symbols and notations used for the system flow diagrams are not universal, and may differ among different WSPs. It is important to try and consistently use particular symbols/notations in a WSP.

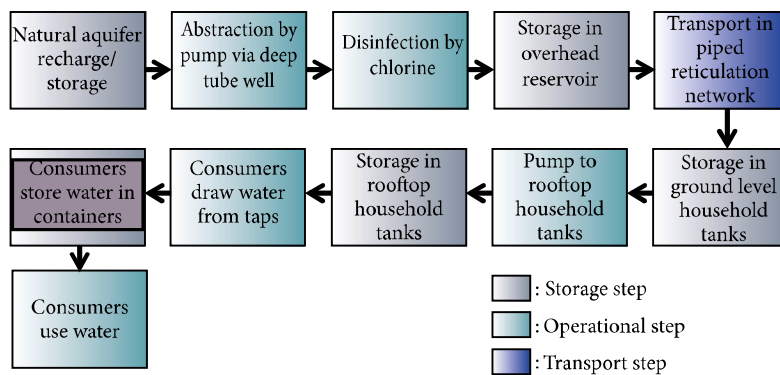


Figure 2: Example flow diagram for urban piped water supply system

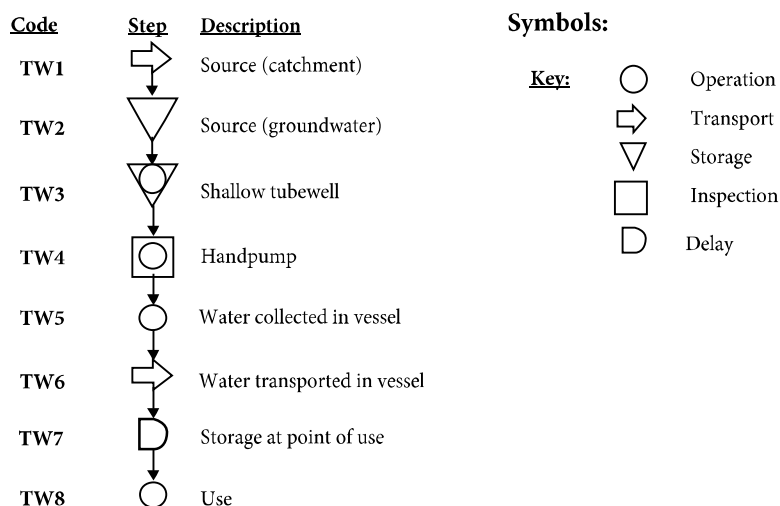


Figure 3: Example flow diagram for hand tubewell rural water supply

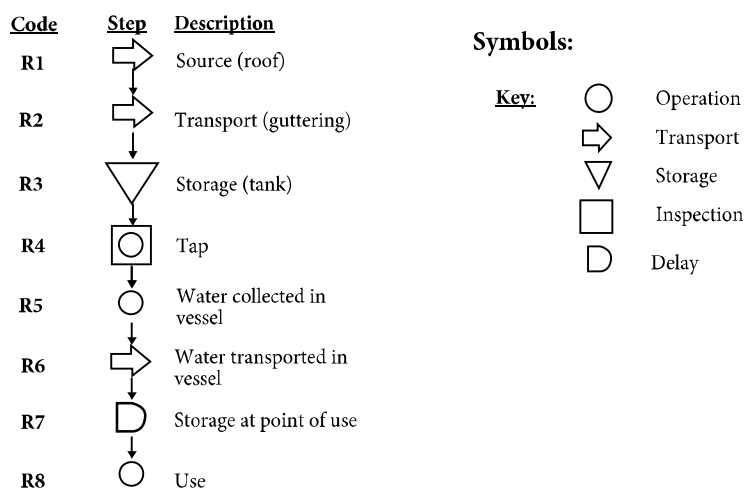


Figure 4: Example flow diagram for a rainwater harvesting system

Step 3: Risk assessment, prioritization and control

Step 3 of WSP is “Risk assessment, prioritization and control”. The objective of this step is to assess the risks associated with the hazards identified during system description. Table 2 provides some useful information in identifying hazards in a drinking water supply system.

Table 2: Information helpful to identifying hazards in a water supply system

Components	Important Considerations
Catchment	<ul style="list-style-type: none"> • Geology and Hydrology (e.g. type of aquifer, nature of river flow) • Nature, intensity and pattern of development and land use (e.g. presence of industries within source water catchment) • Competing water uses (e.g. use of groundwater for irrigation) • Planned future development
Surface Water	<ul style="list-style-type: none"> • Type of water body (river, lake, reservoir, etc.) • Flow and reliability of source • Sources of contamination • Physical, chemical and microbial quality of water • Level of protection • Present and planned future uses of water
Groundwater	<ul style="list-style-type: none"> • Type of aquifer (confined, unconfined) • Permeability, storage capacity • Direction of flow • Recharge potential and level of abstraction • Physical, chemical and microbial quality of water
Water Abstraction System	<ul style="list-style-type: none"> • Type of intake (for surface water) and conveyance (e.g. to treatment plant) system • Type of pumps used (for groundwater) and nature of pump operation (e.g. continuous or intermittent) • Type of hand tubewell and tubewell platform
Treatment	<ul style="list-style-type: none"> • Treatment processes • Efficiency of removal of impurities • Removals of pathogens by disinfection • Disinfectant residuals • Quality of treated water
Distribution System	<ul style="list-style-type: none"> • Reservoir design (central, household) • Distribution system design, hydraulic condition • Nature of supply (intermittent, continuous) • Leakage, cross connection • Quality of joints, service connection • Intervention by consumers (piercing, pumping etc.) • Backflow protection
Transportation, Storage and Use	<ul style="list-style-type: none"> • Transportation of water from water point to household/user level • Overhead tank and underground reservoir at household level for water storage • Storage at household level; type of container, duration of storage • Household level treatment (e.g. boiling, filtration) • Hygiene practice among water users

For risk assessment, it is important to identify the locations in the water supply system which are most susceptible to hazards which could cause contamination of water supply. These locations are often called “critical control points” and whilst they are typically system-specific, the most common generic critical control points in water supply systems are listed in Table 3.

A structured approach like this is important to ensure that all areas of greatest risk are identified. The overall assessment of the drinking water system should consider any historical water quality data to help understand source water characteristics and drinking water system performance, both over time and following specific events (e.g. floods).

Table 3: Critical quality control points in a water supply system

Water Supply Systems	Critical Control Points
Surface and Ground water based Piped Water Supply	<ul style="list-style-type: none"> • Water quality at source • Intake points • Treatment units • Distribution system (e.g., leakage, unauthorized intervention, pressure within the distribution system) • Storage reservoir • Storage of water in houses and hygiene practice
Hand pump Tubewells	<ul style="list-style-type: none"> • Water quality at source • Priming of tubewell • Location of tubewell (e.g., distance of well from sources of contamination) • Platform (e.g., leakage and breakage) • Water collection system/method (e.g., containers) • Storage of water in houses and hygiene practice
Dug Well	<ul style="list-style-type: none"> • Quality of water of upper layer of the aquifer • Water collection system • Location of dug well (e.g., distance of well from sources of contamination) • Apron (e.g., leakage and breakage) • Water collection system/method • Storage of water in houses and hygiene practice
Pond Sand Filter	<ul style="list-style-type: none"> • Quality of water at source • Treatment system/units • Operation and maintenance of the system • Water collection system • Storage of water in houses and hygiene practice
Rainwater Harvesting	<ul style="list-style-type: none"> • Catchment (roof), gutters, etc. • Reservoir • Collection system of water from reservoir • Storage of water in houses and hygiene practice

The major tasks involved in this step are:

- (A) Hazard identification and risk assessment;
- (B) Identification of controls and re-assessment of risks with controls;
- (C) Prioritization of remaining (residual) risks

The following section describes the processes and methods used to accomplish these tasks.

(A) HAZARD IDENTIFICATION AND RISK ASSESSMENT

A “**hazard**” is a biological, chemical, physical or radiological agent in water, or condition of water, with the potential to cause an adverse health effect; it is synonymous to “contaminant”. Identification of potential hazards to a water supply system includes identification of specific hazard (e.g. chemicals, bacteria, viruses, protozoa) and the sources of hazards (e.g. sewers, onsite sanitation, drains, industries, etc.).

A “**hazardous event**” is a process whereby a hazard/contamination is introduced into a water supply system. For example, bacteria/ pathogen present in the pit of the latrine in a rural area is a “hazard”; when bacteria/pathogen travels through soil and contaminates the nearby tubewell water, it is considered an “hazardous event”. Similarly, arsenic present in sediments in an aquifer is a “hazard”; when under favorable geochemical conditions, the arsenic moves from sediment to water and contaminates the water (that is withdrawn through tubewell), it is a “hazardous event”.

As shown at the beginning of Step 3, hazard identification requires a technical understanding of the various steps in collection, treatment, distribution, storage and use of water and the pathways that may cause contamination. It should be done in an inquisitive manner asking questions like:

- What could do wrong in the water supply system?
- How could the water be contaminated and where?
- Is the hazard ever-present or is it only related to a specific event?
- What has gone wrong in the past?
- Who could make a mistake that could lead to contamination of water?

To identify a hazardous event in any water supply system, it is important to consider the “source-pathway- receptor” model of contamination. In this model, the source is the source of the hazards, the receptor is the water supply (e.g. for a

distribution system, pipes of the distribution system are the receptor) and pathways are the means by which the hazards can leave the 'source' and reach the 'receptor'.

Every hazardous event follows a source-pathway-receptor model:

- The hazard has a source;
- Something happens (an event) to release the hazard or allow the hazard to move;
- There is a pathway by which the hazard moves; and
- There is a hazard receptor (the hazard ends up somewhere).

Hazard and Risk Analysis:

“**Risk**” is a measure of the amount of harm that an identified hazard might cause to exposed populations and is measured by likelihood (or frequency - how often a hazard might harm an exposed population) and the severity (impact) of the hazard. Severity is a function of the number of people affected and the likely health impact on those affected people.

Example 1 - Likelihood: If a pit latrine is located within 10 m of a shallow tubewell, the likelihood of pathogens traveling from the pit to the tubewell water is “high”. However, if the pit latrine is located 50 m from the shallow tubewell then the likelihood of pathogens reaching the tubewell water is less, probably “low”.

Example 2 – Severity: If a hazardous event causes a pathogen to contaminate a water supply, the impact could be severe (with the level of severity depending on the number of people served by the water supply system). However, if the hazard is dissolved iron (with no adverse health impacts) the impact would be less severe (only aesthetic problem faced by consumers).

Hazard and risk analysis is the process of collecting and evaluating information on hazards and the conditions (i.e. hazardous events) leading to their presence in a water supply, and then deciding which are the most significant and should be prioritized in the WSP. The result of the risk analysis of hazards is usually expressed in the form of a “risk score” (discussed in approach 2 below).

Different ways to do risk analysis:

There are three main approaches to risk assessment:

(1) Simple risk assessment

This approach involves using qualitative judgment (of the people/team involved in risk assessment) to:

- Assess the hazards and hazardous event(s) in the system;
- Determine whether they are under control; and
- Document whether those events need “urgent attention”.

Table 4 shows the meaning of different risk descriptions of a “simple decision approach”. This approach is more suited for small-scale water supply system.

Table 4: Simple risk prioritization (Team based decision approach)

Description	Meaning	Notes
High (H)	Hazard presents a clear health risk to water users and should be addressed with “high” priority	The risk should be assessed further and control measures should be identified to address the risk. For example, presence of a pit latrine close (e.g. within 10 m) to a shallow tubewell poses a clear risk of water contamination by pathogen. Similarly, the presence of high arsenic concentrations in an aquifer to be used as the source for a pourashava water supply clearly poses a health risk.
Moderate (M)	Hazard presents a “possible risk” that should be investigated further by the WSP Team	The risk may require further study to understand if the event really is significant risk or not. For example, for a tubewell that is producing arsenic-safe water (for which the WSP is being developed), the presence of tubewells with high concentrations of As in the neighboring community would require further consideration (e.g. regular monitoring to detect As contamination in tubewell water).
Low (L)	Hazard presents a “low or insignificant” risk, and not a priority.	The risk will be described and documented as part of a transparent and diligent process and will be reviewed in future years as part of the WSP review. For example, pit latrines are currently located far away (e.g. over 50 m) from the tubewell but new ones might be built closer in the future.

(2) Semi-quantitative assessment

This is the preferred approach for many large or more sophisticated urban utilities. Risk is assessed by two factors:

- Likelihood of occurrence of a hazardous event, and
- Impact of the hazardous event.

The risk is the product of the scores for each of these factors i.e.

$$\text{Risk Score} = \text{Likelihood} \times \text{Impact}$$

There are two key considerations to make in using this approach

- The definitions of the types of likelihoods and impacts;
- The score above which a risk is deemed unacceptable and needs to be controlled.

The first step in semi-quantitative assessment is to assess “raw risks” of given hazards/hazardous events without any existing controls in place. This first step checks the raw risks and reemphasizes the importance of controlling high risks from hazards/hazardous events.

Calculating risk scores and categorization:

The “risk score” is calculated by multiplying “likelihood” value by “impact” value. Table 5 defines “likelihood” and “impact” from which values are derived. Likelihood is defined as one of: almost certain, likely, moderately likely, unlikely and rare. Impact is categorized as one of: catastrophic, major, moderate, minor, and insignificant.

Table 5: Description of Likelihood and Impact

Likelihood	Description
Almost certain	Once a day
Likely	Once per week
Moderately likely	Once per month
Unlikely	Once per year
Rare	Once every 5 years

Impact	Description
Catastrophic	Potentially lethal to large population
Major	Potentially lethal to small population
Moderate	Potentially harmful to large population
Minor	Potentially harmful to small population
Insignificant	No impact or not detectable

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Each “likelihood” and “impact” definition is assigned a number from lowest to highest risk. So for likelihood, values go from 1 for “rare” to 5 for “almost certain” and for impact values go from 1 for “insignificant” up to 5 for “catastrophic”.

The minimum risk score is 1 (rare x insignificant) and the maximum risk score is 25 (almost certain catastrophic) and there are many combinations in between which are set out in a table. Table 6 shows these combinations. From these scores, risk classifications are derived, so:

- ≤ 5 indicates a “low risk”;
- >5 and <15 indicates “medium risk”, and
- ≥ 15 indicates “high risk”.

Table 6 also provides detail definition of the five different categories of “likelihood” and “impact” to help WSP Teams to appropriately categorize particular hazards/ hazardous events.

Table 6: Semi-quantitative risk scoring: risk matrix

		Impact				
		Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Likelihood	Almost Certain (5)	5	10	15	20	25
	Likely (4)	4	8	12	16	20
	Possible (3)	3	6	9	12	15
	Unlikely (2)	2	4	6	8	10
	Rare (1)	1	2	3	4	5

Risk Severity		
Low	Medium	High
≤ 5	6-14	≥ 15

Table 6: Contd.

Likelihood	
Rating	Description
Almost Certain (5)	Is expected to occur in most circumstances; has been observed regularly in the field; confirmed by water quality data.
Likely (4)	Will probably occur in most circumstances; has been observed occasionally in the field; confirmed by water quality data.
Possible (3)	Might occur sometimes; has been observed occasionally in the field; no significant water quality data trends that confirm risk.
Unlikely (2)	Could occur at some time; has not been observed in the field; no water quality data trends that confirm risk.
Rare (1)	May occur in exceptional circumstances; has not been observed in the field; water quality data do not indicate any risk.

Impact	
Rating	Description
Insignificant (1)	Negligible impact on water quality, service delivery or normal operations.
Minor (2)	Minor water quality impact for a small percentage of consumers some manageable disruptions to operation;
Moderate (3)	Minor water quality impact for a large percentage of consumers clear rise in complaints and dissatisfaction regulator interest; significant but manageable modification to normal operations; increased operational costs;
Major (4)	Major water quality impact for a small percentage of consumers large number of complaints; significant level of customer concern; systems significantly compromised with abnormal operation if at all; high level of monitoring.
Catastrophic (5)	Major water quality impact for a large percentage of consumers illness in community associated with the water supply; litigation by customers;

NB: The subjective approach to categorizing “likelihood” and “impact” means that risk scores estimated for a particular hazard/hazardous event may differ, depending on assessor perceptions. Nevertheless, the risk score provides a clear picture of relative risks from different hazardous events for a particular water supply system, and also possible reductions in risk due to implementation of control measures (discussed in the next Section).

Exercises on semi-quantitative risk scoring and categorization from Table 6

Exercise 1A:

For a tubewell-based community water supply system in a rural area, possible contamination of well water from leaching from pit latrines is considered to be a hazardous event. Estimate the “raw risk” score and risk category for this hazardous event, ignoring existing control measures (i.e. distance between latrine and tubewell).

Solution 1A:

We know, Risk = Likelihood x Impact

In order to estimate risk score, we first need to assign numerical values to “likelihood” and “impact”. In the absence of any control measure [so adequate distance (> 10 m) between pit latrine and tubewell is not maintained], leaching from the pit latrine is very likely to contaminate the well water on a regular basis. As a result, the “likelihood” of occurrence of this hazardous event may be categorized as “almost certain” (see Tables 5 and 6) and assigned a numerical value of 5 (see Table 6).

In terms of impact of this hazardous event, it would contaminate the tubewell water with pathogens that could result in the spread of water-borne diseases among community residents. Based on definitions provided in Tables 5 and 6, the “impact” could be categorized as “major”, and assigned a score of 4 (Table 6).

So risk score = $5 \times 4 = 20$ which is >15 ; so risk is “High”.

Exercise 1B:

Drinking water is supplied to a pourashava from groundwater extracted via deep tubewells (DTWs) and through a piped distribution system recently constructed with good quality control measures in place. The groundwater contains high concentrations of both dissolved iron (10 mg/l) and arsenic (1.0 mg/l). Water supply is intermittent as DTW pumps are operated for only a few hours each day; so there is risk of ingress of contaminant when there is low/no pressure in the system. Ignoring any control measure, calculate the “raw risk” score and category for these three hazardous events: (a) high Fe concentration in groundwater, (b) high As concentration in groundwater; and (c) ingress of contaminants to the distribution system.

Solution 1B:

We know, Risk = Likelihood x Impact

(a) High concentration of iron in groundwater:

In the absence of any control measure [e.g. treatment plant], the consumers will always get water with high concentrations of Fe, so the “likelihood” of this hazardous event is “almost certain” (see Tables 5 and 6) and assigned a value of 5.

This hazardous event would cause aesthetic problems, including poor appearance (due to presence of iron flocs), and staining of clothes and

utensils but no adverse health effects would be expected. Thus “impact” would be “moderate” (minor water quality impact for a large percentage of customers) and assigned a score of 3 (see Table 6).

So risk score = $5 \times 3 = 15$ which is ≥ 15 ; so risk is “High”.

(b) High concentration of Arsenic in groundwater:

As for arsenic, in the absence of any control measure [e.g. treatment plant], the consumers will always get water with high concentrations of As; so the “likelihood” is “almost certain” (see Tables 5 and 6) and assigned a value of 5.

This hazardous event could cause major adverse health effects, including arsenicosis and risk of developing cancer so the “impact” should be “catastrophic” (major water quality impact for a large percentage of customers) and assigned a score of 5 (see Table 6).

So risk score = $5 \times 5 = 25$ which is > 15 ; so risk is “High”.

(c) Ingress of contaminants into distribution system during low/no pressure:

In the absence of any control measure [e.g. maintaining continuous pressure in the distribution system using overhead storage tanks], occasional ingress of contaminants into the distribution system is likely. However, since the distribution system was constructed recently (with good quality control) it should have few leaks or faulty joints. As a result, the “likelihood” of occurrence of this hazardous event may be categorized as “possible” (see Tables 5 and 6) and assigned a value of 3.

This hazardous event is likely to cause “minor water quality impact (e.g. suspended solids in water) for a large percentage of customers” (assuming that the pipes are not close to sources of fecal matter such as drains and pit latrines). Thus, based on definitions in Tables 5-6, the “impact” could be categorized as “moderate” and assigned a score of 3 (Table 6).

So risk score = $3 \times 3 = 9$ which is > 5 and < 15 ; so risk is “Medium”.

This exercise allows ranking of the hazardous events based on risk score. Here, presence of As in water ranks first (i.e. highest risk), and should be addressed with the highest priority.

(3) Qualitative assessment

An even simpler qualitative approach of risk analysis involves categorizing “likelihood” into three classes: Likely, Possible and Unlikely; and categorizing “impact” also into three categories: No/minor impact, Moderate impact, and Major impact. As shown in Table 7, this categorization results in nine combinations of “likelihood” and “impact” that fall under three levels of “risk” – Low, Medium and High. Table 7 also provides detailed definitions of different categories of “likelihood” and “impact”. Estimation of risk categories using the two different approaches in Tables 6 and 7 should yield very similar results.

Table 7: Qualitative Risk Assessment: Risk Matrix

		Impact		
		No/minor Impact	Moderate Impact	Major Impact
Likelihood	Likely	Medium	High	High
	Possible	Low	Medium	High
	Unlikely	Low	Low	Medium

Likelihood	
Descriptor	Description
Likely	Will probably occur in most circumstances; has been observed regularly (e.g. daily to weekly)
Possible	Might occur at some time; has been observed occasionally (e.g. monthly to quarterly or seasonally)
Unlikely	Could occur at some time but has not been observed; may occur only in exceptional circumstances.

Impact	
Descriptor	Description
Major Impact	Major water quality impact; illness in community associated with the water supply; large number of complaints; significant level of consumer concern; significant breach of regulatory requirement.
Moderate Impact	Minor water quality impact (e.g., not health related, aesthetic impact) for a large percentage of consumer clear rise in complaints; community annoyance;
No/minor Impact	Minor or negligible water quality impact (e.g., not health related, aesthetic impact) for a small percentage of customers; some manageable disruptions to operation; rise in complaints not significant.

Exercises on qualitative risk scoring and categorization from Table 7

Exercise 2A:

For the same water supply system and hazardous event described in Exercise 1A, estimate risk category following the qualitative approach presented in Table 7.

Solution 2A:

We know, Risk = Likelihood x Impact

As discussed in Exercise 1A, in the absence of any control measure, leaching from the pit latrine is very likely to contaminate the well water on a regular basis so this hazardous event is “Likely” to occur.

This hazardous event would contaminate tubewell water with pathogens that could spread water-borne diseases among the community so “impact” would be “major”.

So with likely occurrence and major impact, the risk would be “High”.

Exercise 2B:

For the same water supply system described in Exercise 1B, estimate risk categories for the three hazardous events: (a) high Fe concentration in groundwater, (b) high As concentration in groundwater; and (c) ingress of contaminants to the distribution system, following the qualitative approach in Table 7.

Solution 2B:

We know, Risk = Likelihood x Impact

(a) High concentration of iron in groundwater:

As in Exercise 1B, in the absence of any control, the consumers will continuously get water with high iron concentrations, so the occurrence of this hazardous event will be “Likely”. As in Exercise 1B, this event would only give rise to aesthetic problems with no adverse health effect, so the “impact” would be “minor”.

So with likely occurrence and minor impact, the resulting risk is “Medium”.

(b) High concentration of arsenic in groundwater:

As in Exercise 1B, in the absence of any control, the consumers will continuously get water with high As concentrations, so the occurrence will be “Likely”. As in Exercise 1B, this could cause major adverse health effects, so the “impact” should be “major”.

So with likely occurrence and major impact, the resulting risk is “High”.

(c) Ingress of contaminants in the distribution system during low/no pressure:

As in Example 1B, in the absence of any control measure, the likelihood is for occasional ingress of contaminants into the distribution system, so occurrence of this hazardous event would be “Possible”. As in Exercise 1B, this hazardous event is likely to cause “minor water quality impact (e.g. suspended solids in water) for a large percentage of customers”, so “impact” would be “moderate”.

So with possible occurrence and moderate impact, the resulting risk is “Medium”.

(B) IDENTIFICATION OF CONTROLS AND RE-ASSESSMENT OF RISKS WITH CONTROLS

A “control measure” is any action or activity (or physical measure) that can be used to prevent or eliminate a hazard/hazardous event or reduce it to an acceptable level. Whilst identifying hazards and evaluating the risks, existing and potential control measures are identified as a part of developing a WSP. As part of this process, the effectiveness of existing controls should be determined. Depending on the type of control, this could be done by site inspection, manufacturer’s specification, or monitoring data. The risks should then be recalculated (likelihood and impact as before) accounting for each existing control measure. If the effectiveness of the control is not known during the initial risk assessment, then the risk should be calculated as though the control was not working.

Any remaining (residual) risks, after the existing control measures have been taken into account, which are considered to be unacceptable, should be investigated in terms of what additional corrective actions could be taken. After

adaptation of additional/new control measures, the risks should be once again recalculated in terms of likelihood and impacts taking into account the effectiveness of each control. It is important that significant risks that do not have controls are highlighted as remaining significant risks in that water supply system.

Exercises to reassess risks with control measures accounted for (using semi-quantitative approach)

Exercise 3A:

For the water supply system described in Exercise 1A, reassess the risk score and category for a situation where the pit latrine is positioned far away (>30 m) from the tubewell – this could be considered a “control measure” preventing fecal contamination of tubewell water. Use Tables 5 and 6 for the semi-quantitative approach.

Solution 3A:

Remember, Risk = Likelihood x Impact

In order to estimate risk score, we need to first determine “likelihood” and “impact” values. Since the pit latrine is located far away from the tubewell, the “likelihood” of this hazardous would be “rare” with a value of 1.

Irrespective of the likelihood, the impact of this hazardous event would still be “major” (i.e. whilst less likely, if pathogens from the pit latrine reach the well it will still spread diseases) with a value of 4.

So remaining (residual) risk score = $1 \times 4 = 4$ which is <5 so risk is “Low”.

Thus, it appears that the existing control measure (i.e. positioning the tubewell and pit latrine far away from each other) reduces the risk significantly. However, as discussed below, the effectiveness of the control measure would need to be validated through collection of evidence (in this case water quality tests) on a periodic basis.

Exercise 3B:

For the water supply system described in Exercise 1A, recalculate the risk score and risk category considering control measures as follows: (a) an arsenic-iron removal plant (AIRP) for removal of arsenic and iron²; (b) good operation and maintenance (e.g. quickly repairing identified/reported leaks) to prevent ingress of contaminants into the distribution system. Use Tables 5 and 6 for the semi-quantitative approach.

Solution 3B:

Remember, Risk = Likelihood x Impact

(a) With control measure - AIRP to remove excess arsenic and iron

This control measure is controlling two risks (iron and arsenic) so the risk assessment should be done for each risk.

(i) iron

Assuming that the AIRP operates as designed, excess iron (i.e. exceeding 1.0 mg/l) in treated/supplied water should be “rare” with a value of 1.

With the lower level of iron (< 1.0 mg/l) in the supply water the “impact” would be less, “insignificant”, with a value of 1.

So remaining (residual) risk score = $1 \times 1 = 1$ which is <5 so risk is “Low”.

Thus, the control measure (installation and use of AIRP) reduces the risk from iron from “medium” to “low”. However, as discussed below, the continued effectiveness of the control measure needs to be validated by collecting evidence (in this case water quality tests) on a periodic basis.

(ii) arsenic

Assuming that the AIRP operates as designed, excess As (i.e. exceeding 0.05 mg/l) in treated/supplied should be “rare” with a value of 1.

With the lower level of As (< 0.05 mg/l) in the supply water the “impact” would be less, “minor”, with a value of 2.

So remaining (residual) risk score = $1 \times 2 = 2$ which is <5 so risk is “Low”.

² for this example, assume that the AIRP operates effectively, and brings down arsenic and iron concentration below the respective national drinking water standards of 0.05 mg/l and 1.0 mg/l, respectively.

Thus, the control measure (i.e. installation of operation of AIRP) reduces the risk significantly (bringing it down from “high” to “low”). However, as discussed below, the effectiveness of the control measure needs to be validated by collecting evidence (in this case water quality tests) on a periodic basis.

(b) With control measure - good operation and maintenance to prevent ingress of contaminants in distribution system during low/no pressure

Ingress of contamination occurs during periods of low/no pressure in the distribution system. Identification of leaks in buried pipe network is difficult so the “control measure” (routine operation and maintenance, including repair of identified leaks) will not be very effective in preventing ingress of contaminants into the distribution system. Therefore, the likelihood of the hazardous event will remain “possible” with a value of 3.

The impact of the hazardous event would also remain “moderate” with a value of 3.

So remaining (residual) risk score = $3 \times 3 = 9$ which is >5 and <15 so risk is “Medium”.

This means that the control measure is not effective in reducing the risk, and additional control/corrective measures/actions (e.g. provision of overhead storage tank that would maintain pressure in the system during non-pumping period) should be considered to reduce the risk.

(C) PRIORITIZATION OF REMAINING (RESIDUAL) RISKS

Risks should be prioritized in terms of their likely impact on the capacity of the system to deliver safe water. High risks (hence high priority) may require system modification or upgrade to achieve the water quality targets. Lower risks (hence lower priority) can often be minimized as part of routine good practice activities.

Any hazardous event classified as “high” risk should already have in place, or as an urgent action, validated controls (or mitigation measures). Where controls are not in place or inadequate then an improvement plan should be drawn up. Any hazard classified as ‘moderate’ or ‘low risk’ should be documented and kept under regular review. Controls for ‘high’ risks may also mitigate other risks.

Risks can only be reassessed and prioritized following validation of control measures. Validation means obtaining evidence that any given control measure is indeed capable of doing what it is intended or claims to achieve. Initial validation of controls can be carried out through intensive monitoring, unless controls have proof of their effectiveness over time. If it is clear that the system needs to be improved to achieve the relevant water quality objectives, an upgrade/improvement plan should be developed and implemented.

Step 4: Operational Monitoring

Monitoring Parameters:

Operational monitoring is a management procedure to ensure that a “control measure” continues to work as intended and that proper and timely corrective actions are taken when operational targets are not met. For example, if installation and operation of an AIRP is the “control measure”, then it needs to be ensured that the AIRP reduces the concentrations of arsenic and iron in treated water satisfying the corresponding national standards. For operational monitoring, it is useful to have both target and action levels. Target levels are often related to national drinking water quality standards, such as arsenic concentration below 0.05 mg/l, or zero FC.

Monitoring of control measures is essential to support risk management by demonstrating that the control measures continue to be effective and that if deviations are detected then actions can be taken in a timely manner to prevent health-based targets from being compromised. These typically require some parameters to be monitored. These parameters can be measurable (e.g. chlorine residual, pH, turbidity, iron or arsenic) or observed (e.g. integrity of fences, vermin-proofing screens, lack of human activity or animals in an exclusion zone). For most control measures, ‘critical limits’ should be defined, beyond which confidence in water safety would diminish and corrective actions must be taken. Effective monitoring relies on establishing:

- What will be monitored?
- How it will be monitored?
- The timing or frequency of monitoring
- Where it will be monitored?
- Who will do the monitoring?
- Who will do the analysis?
- Who receives the results for action?

Corrective Actions:

Corrective actions are to be taken when the results of monitoring at a control point indicate an actual or pending loss of control. A corrective action should be identified for each control that will prevent contaminated water being supplied, if monitoring shows that the critical limit has been exceeded. For example, if monitoring of arsenic concentration at the AIRP plant of a Pourashava shows that arsenic concentration approaching or exceeding the national standard of 0.05 mg/l, then “corrective measures” need to be devised after assessing the reason (system assessment) for the failure of AIRP to reduce arsenic concentration. Monitoring and corrective actions form the control loop to ensure that unsafe drinking water is not consumed. Corrective actions should be specific and pre-determined where possible to enable their rapid implementation.

The following should be systematically considered while devising corrective actions:

- Have corrective actions been documented properly, including assigning responsibilities for carrying out the actions?
- Are people correctly trained and appropriately authorized to carry out corrective actions?
- How effective are the corrective actions?
- Is there a review process in place for analyzing actions to prevent recurrence of the need for a corrective action?

Step 5: Management and Operational Procedures

A management procedure captures and documents required actions under normal and “incident” or emergency conditions (e.g. normal operation of a water treatment plant or operation during flood or in the event of a power failure). An “incident” is an unusual event, which could seriously compromise water quality and requires a significant response. Clear management procedures documenting actions to be taken when the system is operating under normal conditions (Standard Operating Procedures or SOPs) and when the system is operating in ‘incident’ situations are an integral part of a WSP.

Effective management requires actions to be defined to be taken in response to situations that occur during:

- Normal operational period;

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- Predictable incidents;
- Unforeseen events; and
- Emergencies

The management plans should also include:

- Plans and actions, when required, for closing supply and/or issuing “water avoidance” and/or “boil water” orders;
- Monitoring and verification plan as a routine activity; and
- Supporting programmes, such as training, which are important in ensuring water safety.

Management procedures need to be documented alongside system assessment, monitoring plans, supporting programs and communication procedures that are required to ensure safe operation of the system. Documentation of a WSP should include:

- Description and assessment of the drinking water system including programmes to upgrade and improve water delivery;
- Plan for operational monitoring and verification of the drinking water system;
- Water safety management procedures for normal operation, incidents and emergency situations;
- Communication plans; and
- Description of supporting programmes.

WSP Review

It is important that the WSP is reviewed on a regular basis as hazards and hazardous events may change and the condition of control measures may change. The process taken for review would be the same as that shown above.

So this the completion of the five Steps of a WSP as shown in Figure 1, as promoted by the Government of Bangladesh. Figure 1 also shows that there are two additional important activities that should be carried out for a WSP. These are ‘System improvement’ and ‘Supporting programmes.’

2.4 System Improvement

As noted earlier, “high priority” risks may require system modification or improvement to achieve the water quality targets. Based on “risk assessment, prioritization and control” (i.e. Step 3) during the development of a WSP (or at any stage during implementation of a WSP), an “improvement” in the existing “system” may be executed to reduce or eliminate a major risk (e.g., reconstructing a leaking/ damaged tubewell platform, or replacing a leaky overhead tank in a building). After execution of such “system improvements”, the WSP should be amended starting from Step 2 (system description and analysis) to include the improvements.

2.5 Supporting Programmes

Supporting programmes include those activities, which promote and improve the WSP through improving management capacity, skill, knowledge and commitment of staff. It covers a range of activities including training courses, research and development, etc. as well as legal aspects such as a programmes for understanding an organization's compliance/ obligations. Here, the key actions are: (i) identification of the supporting programmes needed for WSP implementation, (ii) review of the existing supporting programmes, and (iii) development of additional programmes (if needed) to address gaps in staff knowledge and skill.

Examples of supporting programmes may include:

- Training and awareness programmes: WSP training, orientation courses, education courses, advocacy meetings, hygiene awareness sessions, etc.
- Research and development: Studies on issues like performance assessment and research for better indicators of contamination.
- SOPs: e.g., O&M manuals and source protection protocols
- Customer satisfaction protocols: call centers, complaints training

For Further Reading

DPHE-ITN (2006) Water Safety Plan for Rural Water Supply System, DPHE-ITN, 2006.

GoB (2011) Water Safety Framework (WSF) in Bangladesh, Govt. of the People's Republic of Bangladesh, Local Govt. Division, LGRD&C, 2011. ISBN 978-984-33-4174-7.

WHO (2011) Guideline for Drinking Water Quality: Fourth Edition, World Health Organization (WHO), 2011.

WHO (2008) Guideline for Drinking Water Quality: Third Edition, World Health Organization (WHO), 2008.

Appendix: WSP Sessional Class Outline

Water Safety Plan (WSP) for a Water Supply System

Introduction:

Water Safety Plans (WSP) may be introduced as a topic (covering 1-2 classes) in an existing environmental engineering sessional class. The students of the sessional class are expected to be familiar with the concept of Water Safety Plans (WSP), which is covered under an environmental engineering theory course taken by the students earlier.

The course teacher may present a brief overview of WSP at the beginning of the class, based on the course material covered in the theory class, focusing on system description and analysis and system assessment (risk analysis).

Objective:

In the class, the students will develop parts of a WSP for a particular water supply system. The objective of this exercise is to familiarize the students with two major components of a WSP: (a) System description and analysis, and (b) Risk assessment.

Specific tasks to be carried out by students:

The course teacher will assist students in identifying a water supply system (or multiple water supply systems, each system to be covered by a “group” of students in the class) for which the WSP is to be developed. The water supply system may be that of: (a) the university; (b) a particular building of the university; (c) particular residential hall of the university; or (d) any residential building. Alternatively, the class teacher may select particular water supply systems for the class.

For the water supply system(s), the students will:

1. Develop a system description, and present the system description in the form of a flow diagram;
2. Carry out system analysis, identifying at least three hazards and hazardous events;

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3. Carry out semi-quantitative risk analysis of the hazardous events and estimate “risk score” and “risk category”. Based on the risk score, the students will prioritize the risks; and
4. The students will propose an appropriate “control measure” for at least one hazardous event, and will re-calculate the “risk score” and “risk category” considering the control measure.

The students will submit a short report summarizing the above tasks and make a brief presentation (group-wise).



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