Source Protection

Session Objectives

- To describe the need for the protection of water sources and resources.
- To define the terms 'source protection' and 'resource protection'.
- To discuss the influences on quality of water in the environment and the importance of human activities on water quality deterioration.
- To describe some of the preventative measures that are applicable to groundwaters.
- To describe some of the preventative measures that are applicable to surface waters.

Source Protection

Introduction

The prevention of water contamination is always preferable to attempting to remove contamination once it has entered the aquatic environment. Whilst it is likely that some contamination events will always occur, a large proportion of drinking-water quality problems can be prevented through: adequate source protection and good water resource management; good design, operation and management of water supplies; and regular and thorough surveillance activities.

The initial selection of a source for drinking-water should ensure that the best source is selected. This can be done by carrying out a thorough analysis of source water quality and making a comprehensive assessment of the vulnerability of the source to contamination. This should obviously be done before any investment is made in construction.

The quality of the proposed source water should be tested under "worst case" conditions (those periods when contamination is most likely to occur such as the start of a wet period or when groundwater levels are raised) whenever possible. A sanitary inspection and pollution vulnerability assessment of the source should also be undertaken under "worst case" conditions.

If the source is contaminated, this may not preclude it's use as a source of drinking-water, as it may still be the best quality source available and/or the best source on other grounds such as cost, availability and quantity. Initial analysis should provide information on the nature of contaminants present and therefore an indication of what treatment processes will be required to remove them prior to distribution. A sanitary inspection should indicate the risk to the source from sources of microbiological contamination in the immediate surroundings of the source and suggest measures that may be taken to protect the source from continued contamination. A pollution vulnerability assessment will provide information on the risk to the source of contamination from a wider perspective and identify potential risk from chemical contamination.

Water source protection

Water source protection is a mixture of localised measures designed to protect individual sources and wider ranging measures designed to protect the larger water resource body. The latter can be on a provincial, national or regional (international) basis. For surface waters, the most appropriate level to protect water sources is though basin management. Depending on the size of the catchment area and water body, this may mean working on a scale ranging from district or provincial level up to international treaties involving several riparian countries (for instance the Nile and Zambezi basins).

As surface water sources and resources are far more open to contamination and potential catchment areas of contamination are generally far larger than for groundwater. Thus, any measures taken to protect surface water resources will generally encompass a far wider geographical region than measures designed to protect groundwater resources.

It is important that both localised and wider measures are undertaken to protect sources used for drinking-water supplies. Local measures are required to ensure that the actual water source is not at risk from contamination in its immediate environment. An example of this is well-head completion measures on the top of boreholes which ensure that the top of the borehole is sealed against the entry of contaminated surface water. Large-scale measures are required to ensure that valuable water sources are not lost because of contamination of the water body some distance away from the drinking-water source. An example of this is the definition of land-use zones around important aquifers to limit potential contamination.

Groundwater protection

Groundwater is an important source of drinking-water. In its natural state, groundwater is generally of high microbiological quality with little or no contamination, although some groundwaters do have high levels of harmful chemicals such as fluoride and arsenic. The relative purity of groundwater in its natural state is largely a result of infiltration through the soil and unsaturated layers of rock. During infiltration attenuative processes such as sorption, mechanical filtration and ion exchange operate which remove bacteria and some chemicals, particularly metals, from the water. However, some chemical compounds, such as nitrate, are not easily attenuated and once in the sub-surface aquatic environment are highly persistent and mobile. It is thus important that such chemicals are prevented from entering aquatic systems.

Once an aquifer is contaminated, as the movement of water through sub-surface systems relative to their volume is slow and residence times are lengthy, the natural processes of removal by dilution and discharge to surface waters may be extremely long (decades, centuries or millennium). Thus prevention of contamination of groundwaters by persistent mobile contaminants is an essential element in the protection of groundwater resources. A further complication is that many attenuative processes in the saturated zone are reversible and whilst initially contaminants may be removed from solution through, for instance sorption, at a later date they may be desorped and re-enter the water. This is a common problem in industrial cities in western Europe, where initial development led to a decrease in the water and subsequent attenuation of contaminants in the unsaturated zone. Subsequent development has occurred elsewhere using different water sources leading to a recovery of groundwater levels and desorption of contaminants and groundwater pollution. For instance there has been a noticeable increase in the levels of heavy metals in recovering groundwaters beneath London.

Different types of aquifers are vulnerable to contamination to differing degrees. Generally where aquifers are overlain by a substantial unsaturated zone and have high primary porosity and reasonable permeability, they tend to be less vulnerable to pollution. Aquifers where water is primarily held in secondary porosity (fissures and joints) tend to be more vulnerable to contamination as the water has less opportunity to undergo attenuative processes which remove contaminants.

This has led the concept of "Groundwater Protection Zones" where acceptable land uses are defined in order to protect the underlying groundwater. These zones were originally developed in Western Europe, particularly Germany and the Netherlands, to prevent contamination of groundwater supplies by pathogens and thus reduce the incidence of water borne diarrhoeal diseases. The delineation of groundwater protection zones is done by establishing the length of time a substance or organism takes to become non-harmful and the distance this represents under groundwater flow conditions.

Microbiological groundwater protection zone are established on the basis that the vast majority of pathogenic bacteria die off within 50 days of being in groundwater under normal conditions. Thus by establishing the distance travelled by groundwater in 50 days for a particular area, a zone can be defined from the abstraction point.

The definition of zones for chemical protection has also been attempted but this has been far less successful than the delineation of microbiological zones. This is because, unlike microbiological survival rates, it has proved extremely difficult to establish or even estimate the half-life of many chemicals in groundwater. Not only is there a vast number of chemical compounds which may be found in water, but groundwater and aquifers (particularly hard rock aquifers) frequently have a complicated chemistry themselves which may interact with pollutants and extend or reduce half-life. A 400-day isochron has been suggested in some quarters as being sufficient, but in reality far more work is needed in this area and chemical persistence will vary with different chemicals and aquifers.

Groundwater Protection Zones may take many shapes. They are very rarely simple circles drawn with an abstraction point as the centre. There are many factors which will influence the shape of the zone: the nature of the aquifer (which are very rarely isotropic); the number of rivers in the zone; the condition of rivers (whether influent, effluent, perched or changing); and the number and location of other abstraction points within the zone.

Surface waters which overlie an aquifer will extend the zone along its course upstream as contaminants are likely to move more quickly in surface water. It is important to establish what relationship the river bears to the aquifer, as obviously where a river is supplied by the aquifer the protection zone need not be as extended as when the river recharges the aquifer. However, it is always likely that a river will be influent to an aquifer at some point along its course. Even under effluent conditions there will be river-groundwater interaction and the extension of a zone some way along river which is recharged by the aquifer is always to be recommended. The more rivers associated with the aquifer, the greater the distortion and extension of the zone.

Within the protection zone, land use may be restricted to non-polluting activities and ensure that any discharges within the zone meet stringent quality standards. This may be problematic where there is intensive agriculture with widespread use of inorganic fertilisers and pesticides. In these cases, permitted application loads may be introduced and groundwater quality monitored. In these circumstances is often found that producers can reduce applications whilst maintaining yields, although it is possible that some form of compensation for loss of production may have to be provided. Where intensive animal production is practised, adequate isolation and treatment of slurries should be carried out by the farmer and leakage to groundwater minimised.

Surface Water Protection

Surface waters are particularly vulnerable to contamination from agricultural, industrial and municipal sources. Surface water bodies receive wastewater from industrial and municipal sources, agrochemicals may leach into them, air-borne pollutants may dissolve in surface water and they receive overland run-off which washes surface debris. As a result, all surface waters require treatment before they are supplied for drinking-water, whether the source is a river, lake or reservoir.

There are a number of interventions which will help to protect the quality of surface waters, principal amongst these are: land-use control within the catchment; and proper siting of intake structures away from potential sources of pollution and preferably upstream of them; treatment of effluent and discharges leaving industrial plants and municipal sewage treatment works, and; the establishment and enforcement of effluent quality standards.

Where surface water is used as a source of drinking-water, it is appropriate to ensure that land use within the catchment is controlled and preferably limited to activities which are relatively non-polluting. This can be problematic as some activities may already be established which do cause pollution and in these cases, adequate standards of effluent quality should be established and enforced.

Land-use control has tended to be more effective when applied to artificial reservoirs, principally because in many countries these have been located away from intensive human activity. However, land-use controls may be difficult to introduce as the creation of a large body of water may attract industry which will have effluent discharges. Reservoirs may promote intensive arable agriculture which utilises inorganic fertilisers and pesticides which may pollute the reservoir.

In many countries, standards have been or are being developed and enforced governing the quality of effluent that may be discharged into a river or standing body of water and in many countries, national bodies concerned with water are trying to shift the onus onto producers to treat wastewater prior to discharge - the 'polluter pays' principle. However, few countries have managed to enforce compliance with these standards and large-scale pollution continues. In many countries the penalties for exceeding quality standards are minimal and as the cost of installing treatment processes in the plant greatly exceed the accumulated cost of fines, there is little incentive for the producer to invest in treatment technology. This situation is often exacerbated by the time it takes for cases involving pollution to reach court, further reducing the real cost to the producer.

The rigorous enforcement of compliance with effluent quality standards backed up with adequate legislation which has penalties which reflect the severity of the pollution event will make a significant contribution to the improvement in surface water quality. However, positive influence should also be exerted to assist industry to employ discharge treatment in their plants. This may include awareness raising in the industry sector, technical advice concerning technology choice and may also involve other incentives to industry, such as tax breaks or subsidies, to promote the use of treatment of effluents.

Sediments in surface waters also interact with pollutants in the aquatic environment and can become "reservoirs" of pollution. Where chemical contaminants, particularly metals, are in water there are commonly ion exchange reactions with minerals in the sediment and diffusion of chemicals into the sediment which leads to contaminant build-up. Where there is significant organic material in sediments or the base of streams, metals form organic complexes. These processes may remove contaminants from the water in the short-term, but may be released back into the aquatic environment at a later date, usually in response to a specific flood event. Thus stopping a polluting activity will not lead automatically to a rapid reduction in contaminant concentration in surface waters.

Conclusion

Water source and water resources protection are essential if high quality waters are to remain uncontaminated. Both groundwaters and surface waters are vulnerable to pollution and both require localised and larger-scale actions to prevent pollution of drinking-water sources. Surface waters are open to more immediate pollution and once a pollutant enters a surface water body, it is likely to move rapidly. This means that the pollutant will spread rapidly through the surface aquatic system, although it may make remediation easier, except where there is significant water-sediment interchange.

Groundwater has more natural defences against pollution, however once it becomes polluted it is very difficult to remove the pollutant from the groundwater system and residence times of pollutants may be decades, centuries or longer. Different types of aquifer have differing degrees of vulnerability and thus have different protection requirements.

Both surface and groundwater resources are protected by defining land-use zones around them. This ensures that the establishment of potentially polluting activities is not allowed within a distance that would allow easy pollutant movement. Control of pollution is vital for water source and water resource protection and should be rigorously enforced.

References:

Chilton, J., *Groundwater,* **in** Chapman. D., (ed) *Water Quality Assessments (2nd edition),* Chapman and Hall, London, 1996.

Environment Agency, *Policy and Practice for the Protection of Groundwater*, Environment Agency, London 1996.

Foster, S.S.D. and Hirata, R. *Groundwater Pollution Risk Assessment*, CEPIS, PAHO/WHO, Lima 1988.

Newson, M. *Land, Water and Development*, Routledge, London, 1992.

Source Protection

Presentation Plan

Section	Key Points	OHP
Introduction	• prevention of contamination is important and preferable to treatment • this is achieved through: source protection; water resource management; good design and operation; and surveillance • source selection is important, always select best source available • sources should be assessed under worst case conditions • contaminated sources can still be used	**1**
Water Source Protection	• mixture of localised and broader measures • localised measures prevent contamination in immediate vicinity, sanitary completion measures • broad scale measures prevent pollution of water resources and loss of water sources from distant pollution	**2**
Groundwater Protection	• natural state is very good microbiological quality • chemical quality is sometimes less good • natural removal of contaminants through attenuative processes • once contaminated, removal is expensive and difficult • different aquifers have different vulnerabilities • groundwater protection zones define acceptable land uses around water sources to prevent contamination • definition of zones for microbiological protection are easy, zones for chemical protection are more difficult • shapes of zones vary and surface water-groundwater interactions affect zone shapes and extent	**3,4,5, 6,7,8**
Surface water Protection	• surface water is very vulnerable to contamination from many sources and pollutant move rapidly through surface water bodies • surface water always requires treatment prior to consumption • sources protected through land use control, intake design and pollution control • land use in immediate upstream vicinity of source should be restricted to non-polluting activities • effluent control is important and stringent standards and end of pipe treatment are all required • legislative support and awareness raising in industry are important	**9,10, 11,12 13**

Section	Key Points	OHP
Conclusions	• need source and resource protection to maintain high quality waters • surface water is more vulnerable to pollution than groundwater • pollutants move rapidly in surface water and surface water always requires treatment • once contaminated, remedial action for groundwater is expensive and difficult • control of land use is important for both groundwater and surface water	

Source Protection

- Prevention of contamination is preferable and more sustainable than treatment
- Source selection is important
- Assess potential source of drinking-water under 'worst case' conditions
- Contaminated sources may still be used provided minimum treatment requirements are met

Source Protection Measures

- **Localised:**

  sanitary well seal

  protected intakes

- **Large scale:**

  watershed management

  groundwater protection zones

  water resource management policies

Groundwater Definitions

Aquifer:

Rock or unconsolidated deposit containing water

Porosity:

The percentage of voids in a formation.

Permeability:

Measure of inter-connectedness of pores

Bulk permeability:

Flow through mass as a whole

Intrinsic permeability:

Rate at which rock will allow fluid to pass independent of fluid

Groundwater Protection Zones

- Zones for land use control to prevent contamination
- Based on contaminant persistence and travel time
- Very high flows - possibly reduce travel time as increase attenuation

50 Day Isochron:

- For control microbiological contamination
- Most microbes die within 50 days in groundwater

400 Day Isochron

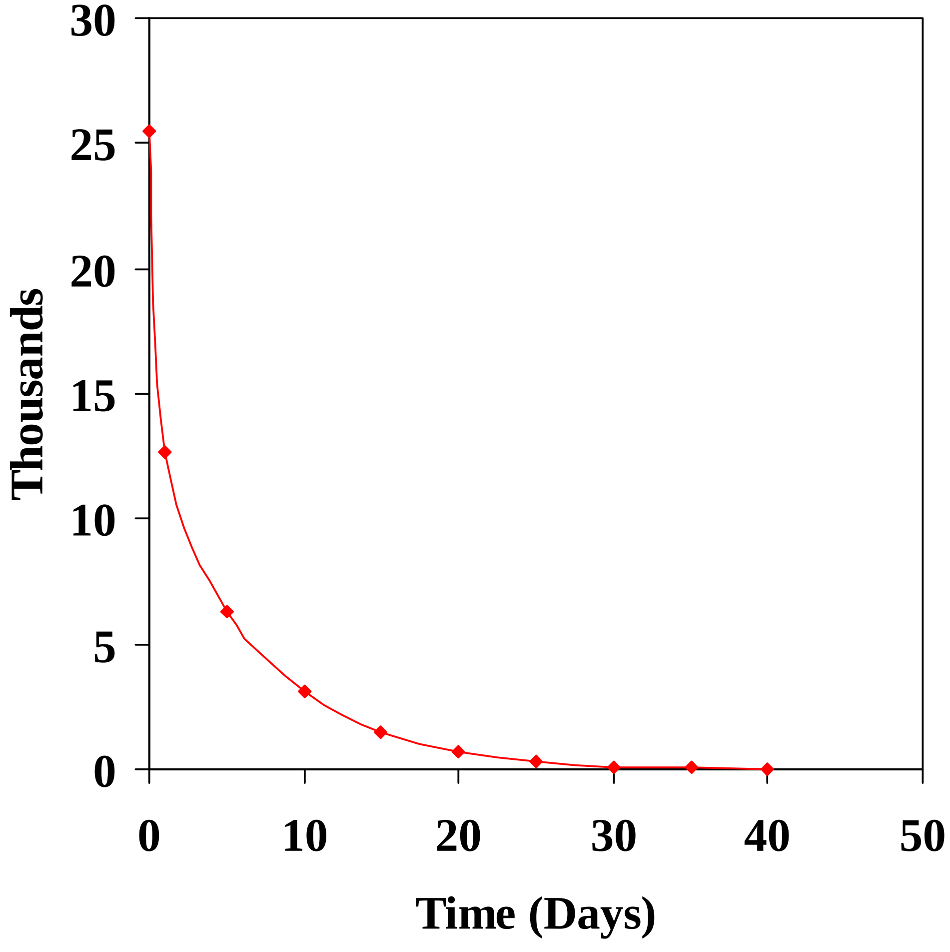
- Used to control persistent chemicals

An alternative is 25 per cent of the recharge area

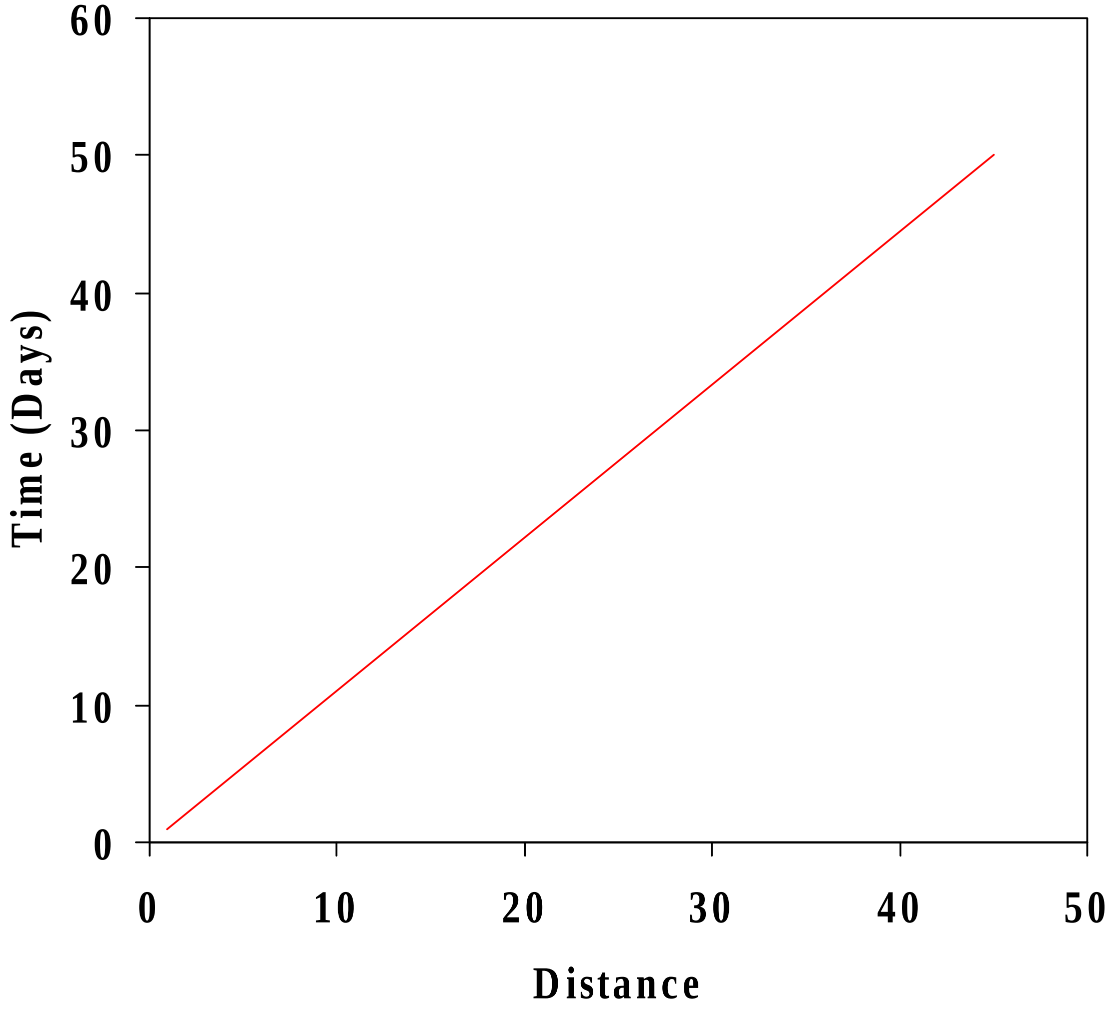
Source Catchment

- Protects the area of long-term annual recharge.

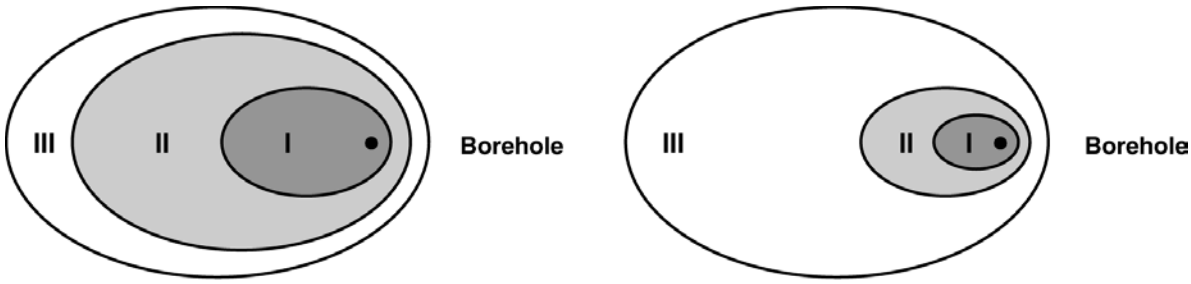
Organism Survival



Distance-time Curve

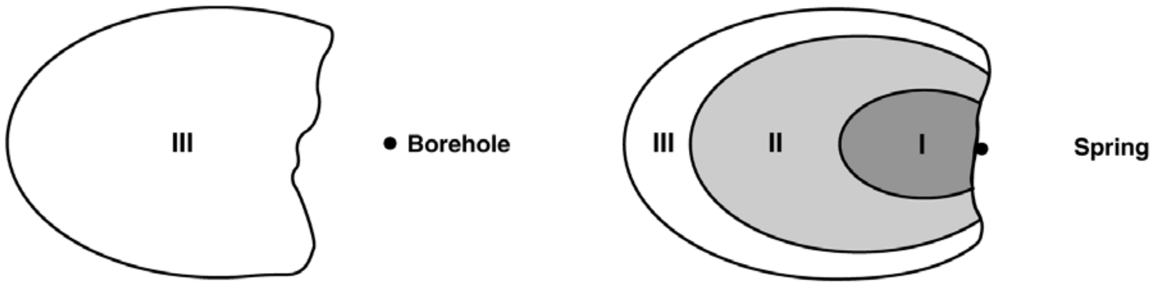


Examples of Protection Zones
(NRA, 1992)



CHALK SOURCE

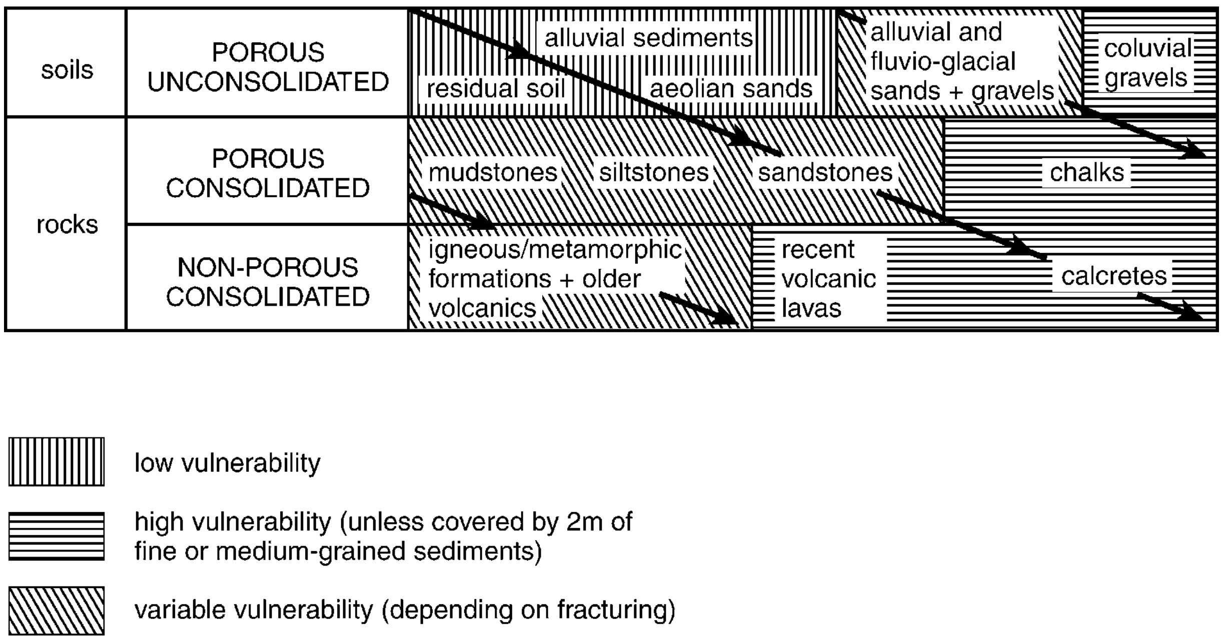
TRIASSIC SANDSTONE SOURCE



CONFINED SOURCE
(Zones I and II not defined)

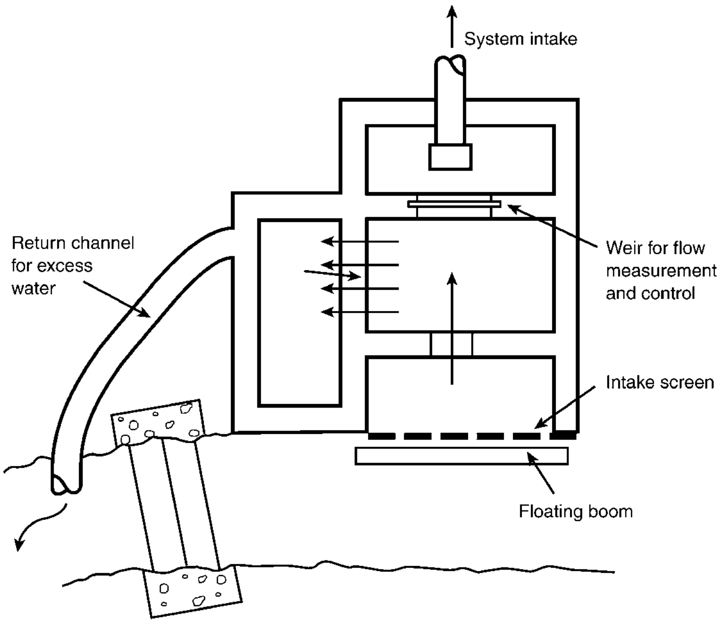
SPRING SOURCE

Simplified lithological classification of geological formation in terms of relative risk of groundwater pollution

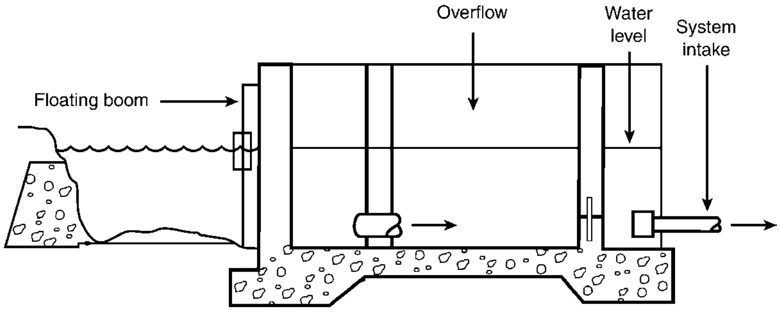


Source: Foster, 1987

Protected River Intake



A. Plan view

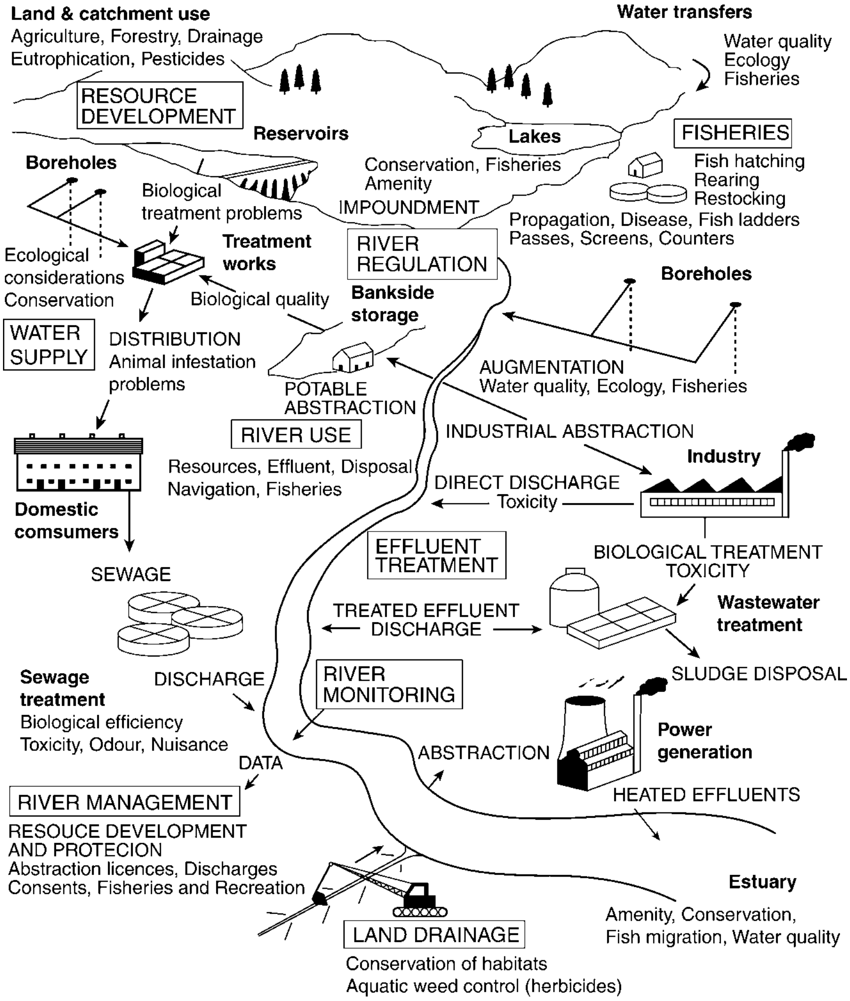


B. Cross Section

Water Resources Protection

- Land use planning and control
- Environmental conservation and habitat protection
- Pollution control

Model of Issues and Activities in Surface Water Management



Source: Newsom, 1994

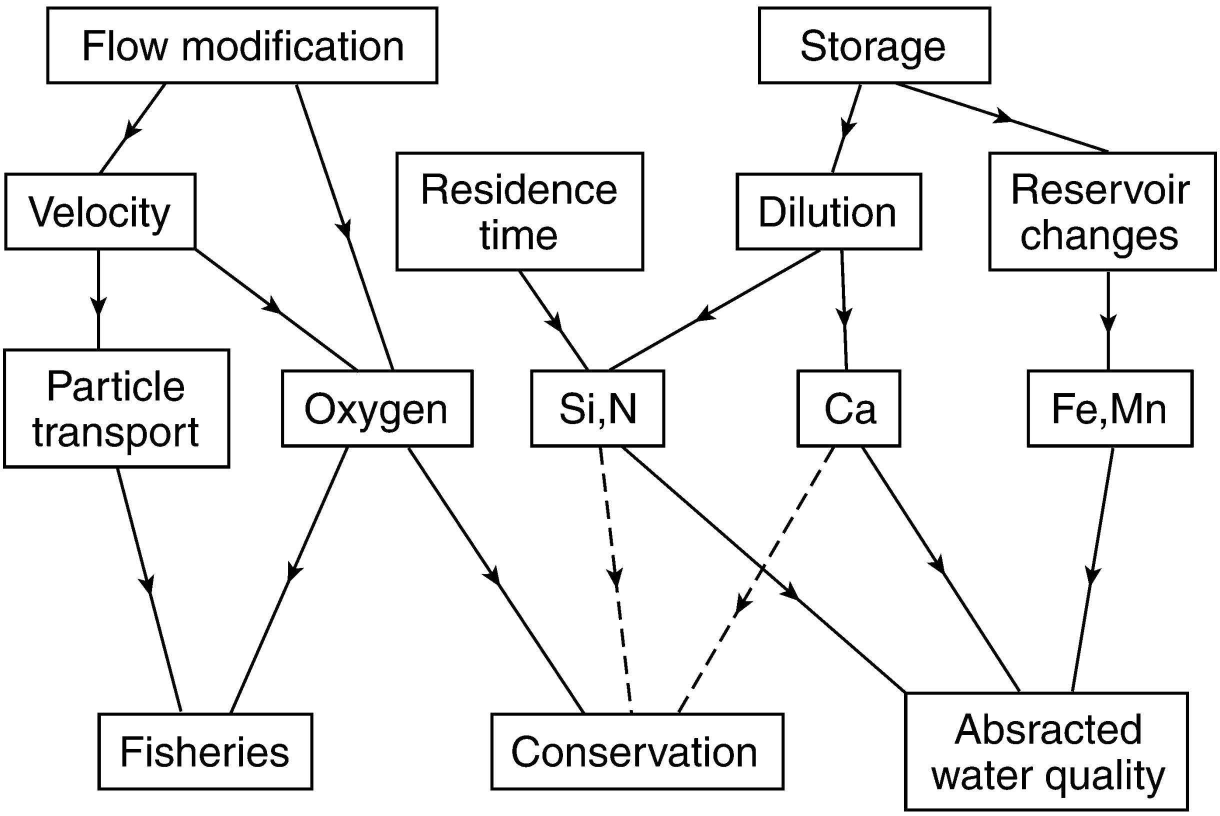
Pollution Sources and Control

- Land-based diffuse:
  land use control
  control on agrochemical use

- Point source:
  effluent quality standards
  enforce compliance

- Air-borne particulate matter
  difficult to control
  international treaties on air
  pollution reduction

Impacts of Intermediate Reservoir Storage in Hydrology and Water Quality



Source: Newsom, 1994