Technical Assistance
HYDROLOGY PROJECT

World Bank & Government of The Netherlands funded

Training module # WQ - 27

Surface Water Quality Planning Concepts

New Delhi, October 1999

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with
HALCROW, TAHAL, CES, ORG & JPS

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1 Module context

This module deals with surface water quality planning concepts. Modules in which prior training is required to complete this module successfully and other available, related modules in this category are listed in the table below.

While designing a training course, the relationship between this module and the others would be maintained by keeping them close together in the syllabus and placing them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course.

No.	**Module title**	**Code**	**Objectives**
1	Basic water quality concepts[a]	**WQ - 01**	• Become familiar with common water quality parameters • Appreciate important water quality issues
2	Basic chemistry concepts[a]	**WQ - 02**	• Convert units from one to another • Understand the basic concepts of quantitative chemistry • Report analytical results with the correct number of significant digits
3	Understanding biochemical oxygen demand test[a]	**WQ - 15**	• Understand the significance and theory of BOD measurement
3.	Oxygen balance in Surface Waters	**WQ - 25**	• Explain the importance of oxygen in water • Identify the main processes of oxygen addition and depletion in surface waters.

a - prerequisite

2 Module profile

Title	:	Surface Water Quality Planning Concepts
Target group	:	HIS function(s): Q2, Q3, Q5, Q6, Q7, Q8
Duration	:	1 session of 60 min
Objectives	:	After the training the participants will • Understand principles of WQ monitoring and assessment • Know of simple data analysis methods
Key concepts	:	• Emission-based and WQ-based Water Quality planning • Reasons for monitoring • Monitoring network • Data analysis
Training methods	:	Lecture and discussion
Training tools Required	:	Board, flipchart, OHS,
Handouts	:	As provided in this module,
Further reading and references	:	• Water Quality Monitoring, ed. J. Bartram and R. Balance • Water Quality Assessment, ed. D. Chapman, E&FN SPON, London

3 Session plan

No	Activities	Time	Tools
1	***Preparations***		
2	***Introduction:***	10 min	OHS
3	***Water Quality Planning*** • Fixed emission limits and control by means of water quality objectives • Planning approach in India	15 min	OHS
4	***Water Quality Monitoring*** • Network design • Example of HP approach	15 min	OHS
5	***Data Interpretation***	10 min	OHS
6	***Wrap up and Evaluation***	10 min	

4 Overhead/flipchart master

OHS format guidelines

Type of text	Style	Setting
Headings:	OHS-Title	Arial 30-36, with bottom border line (not: underline)
Text:	OHS-lev1 OHS-lev2	Arial 24-26, maximum two levels
Case:		Sentence case. Avoid full text in UPPERCASE.
Italics:		Use occasionally and in a consistent way
Listings:	OHS-lev1 OHS-lev1-Numbered	Big bullets. Numbers for definite series of steps. Avoid roman numbers and letters.
Colours:		None, as these get lost in photocopying and some colours do not reproduce at all.
Formulas/ Equations	OHS-Equation	Use of a table will ease horizontal alignment over more lines (columns) Use equation editor for advanced formatting only

Surface Water Quality Planning Concepts

- Water quality planning
- Approach to water quality planning in India
- Water quality monitoring
- Data interpretation

Water Quality Planning

- Fixed emission limits for discharges
- Control by means of water quality objectives

Fixed Emission Limits

- Are fair to all dischargers
- May impose unnecessarily strict conditions
- Assimilative capacity of river is not taken into account

Control Using Water Quality Objectives

- Agree legitimate watercourse uses in consultation with interested parties
- Set water quality objectives based on current or future desired use
- Set water quality standards which allow desired objectives to be met
- Set discharge limits for effluents which do not infringe water quality standards

Water Quality Planning Approach in India

- Large variation in river discharge
- Untreated river water used for domestic supply
- Water quality can not be allowed to degrade
- Uniform emission standards for industries

River action plans

- Measure present water quality
- Determine present and planned beneficial water uses
- Compare most stringent water quality requirement with existing quality
- Formulate action plans
- Take action

Water Quality Monitoring (1)

- Monitoring
  - *To classify water resources*
  - *To collect base-line data*
  - *To detect trends in water quality changes*
- Surveillance
  - *to evaluate suitability for a water use*
  - *to check compliance*

Water Quality Monitoring (2)

- Surveys
  - *To investigate pollution*
  - *To collect data for in-depth analyses*

Monitoring Network

- *Defines type and objective of samples*
- *Defines location of monitoring stations (network density)*
- *Defines monitoring frequency*
- *Defines analytical parameters*

Example Network from HP (1)

- Category / type

  - *monitoring / base-line*

- Objective

  - *background water quality*

- Network Density

  - *one for each stem & one for each major tributary*

- Sampling frequency per year

  - *initially 3 - 4, repeat every 2 - 3 years*

Example Network from HP (2)

- Parameter suite for irrigation water

Parameter Group	Parameter	Water Use
		Irrigation
General	Temperature	X
	Conductivity	X
	pH	X
	Total Dissolved Solids	X
Major Ions	Sodium	X
	Calcium	X
	Magnesium	X
	Chloride	X
	Boron	X
Microbiological	Total coliforms	X

Data Interpretation (1)

- Trend Assessment
  - *Plot data on a time-series graph*
  - *Statistical trend analysis*
  - *Regression and correlation analysis*

NOTE: It is preferable to use the simplest method that gives an acceptable result

Data interpretation (2)

- Calculation of Flux

  - *Example:*

$$BOD = 5\ mg/l = 5\ g/m^3$$

$$Flow = 5\ m^3/s$$

$$Flux = 5 g/m^3\ X\ 5\ m^3/s = 25\ g/s$$

NOTE: Flux is expressed as load; i.e..: mass per unit time

Data Interpretation (3)

- Compliance Assessment

    Water resource:

    - *Compare analytical results with water quality standards (singly or over a period of time)*

    Effluent:

    - *Compare analytical results with effluent permit*

Data Interpretation (4)

- Presentation of Data
  - *Compare data with water quality standards*
  - *Compare data with international standards*
  - *Compare data from different areas*
  - *Show how quality has changed at one point over time (relating this to particular events, if applicable)*

5 Evaluation sheets

6 Handout

Surface Water Quality Planning Concepts

- Water quality planning
- Approach to water quality planning in India
- Water quality monitoring
- Data interpretation

Water Quality Planning

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Fixed Emission Limits

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- Measure present water quality
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Water Quality Monitoring (1)

- Monitoring
    - *To classify water resources*
    - *To collect base-line data*
    - *To detect trends in water quality changes*
- Surveillance
    - *to evaluate suitability for a water use*
    - *to check compliance*
- Surveys
    - *To investigate pollution*
    - *To collect data for in-depth analyses*

Monitoring Network

- *Defines type and objective of samples*
- *Defines location of monitoring stations (network density)*
- *Defines monitoring frequency*
- *Defines analytical parameters*

Example Network from HP

- Category / type
  - monitoring / base-line
- Objective
  - background water quality
- Network Density
  - one for each stem & one for each major tributary
- Sampling frequency per year
  - initially 3 - 4, repeat every 2 - 3 years
- Parameter suite for irrigation water

Parameter Group	Parameter	Water Use
		Irrigation
General	Temperature	X
	Conductivity	X
	pH	X
	Total Dissolved Solids	X
Major Ions	Sodium	X
	Calcium	X
	Magnesium	X
	Chloride	X
	Boron	X
Microbiological	Total coliforms	X

Data Interpretation (1)

- Trend Assessment
  - *Plot data on a time-series graph*
  - *Statistical trend analysis*
  - *Regression and correlation analysis*

  NOTE: It is preferable to use the simplest method that gives an acceptable result
- Calculation of Flux
  - *Example:*

BOD = 5 mg/l = 5 g/m^3

Flow = 5 m^3/s

Flux = 5g/m^3 X 5 m^3/s = 25 g/s

NOTE: Flux is expressed as load; i.e.: mass per unit time

- Compliance Assessment

  Water resource:
  - *Compare analytical results with water quality standards (singly or over a period of time)*

  Effluent:
  - *Compare analytical results with effluent permit*
- Presentation of Data
  - *Compare data with water quality standards*
  - *Compare data with international standards*
  - *Compare data from different areas*
  - *Show how quality has changed at one point over time (relating this to particular events, if applicable)*

Add copy of Main text in chapter 8, for all participants.

7 Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

8 Main text

Contents

Surface Water Quality Planning Concepts

1. Introduction

This module looks at some of the concepts involved in the management of water quality and in particular how the quality of water can be planned, monitored and assessed. It also discusses the approach adopted in India.

2. Water Quality Planning

When planning the quality of surface waters it is important to consider how water pollution control will be implemented to ensure that discharges to water will be adequately managed. For example, it is possible to control discharges to watercourses by one of the following methods:

- fixed emission limits for discharges
- control by means of water quality objectives

In order to show how these methods of control differ, each one will be discussed in greater detail below.

Fixed Emission Limits for Discharges

The ‘fixed emission’ method of pollution control is, at first glance at least, appealing as it is simple and overcomes one of the major difficulties in water pollution control in that it is fair to all dischargers. Thus, two industries with similar processes should have the same limits applied to their discharges and, therefore, each industry will be required to invest a similar amount of money in water pollution control techniques and technologies.

A potential drawback of the system, however, is that it takes no account of the assimilative capacity of the receiving waters. It is therefore possible for an industry discharging to a large estuary to have the same emission limit as a similar industry situated on the headwaters of a small river. This situation will inevitably result in one company (the one situated on the estuary) having strict discharge limits and thus spending more money on water pollution control than may be necessary to protect water quality in the receiving water. This situation can be particularly illustrated by consideration of the concentration of suspended solids in effluents from the two example industries discussed above. There may be little or no requirement to control the release of suspended solids to an estuary which already contains much suspended matter whereas the control of solids is often crucial in upland rivers where fish spawning grounds may be damaged by such material.

Pollution Control Using Water Quality Objectives

Pollution control using water quality objectives, can be illustrated by considering pollution control as applied to a river system. It involves four phases (numbered 1 to 4 below), as follows:

1. Agreeing on Legitimate River Uses

For each separate stretch of river, it is necessary, in consultation with any relevant interested parties, to agree a list of current or potential legitimate uses of the river water.

Examples of such uses would be:

- that the water is used for drinking after conventional treatment
- that the river water is used for abstraction for agricultural use
- that the river water is used to support a fishery
- that the river water is used for recreational purposes
- that the river is used for organised bathing on festivals

At this stage it is important to establish a comprehensive list of current and desired future river uses by consultation with as many interest groups as possible. Examples of such interest groups would be anglers and fisherman, wildlife groups, local residents, water abstractors etc.

2. Setting River Water Quality Objectives

Following the establishment of a comprehensive list of uses, it is necessary to decide on which of the desired future uses should become quality objectives for each defined river reach. In carrying out this task, a number of different factors must be taken into account. The current state of the water body will obviously be relevant as will the resources required to effect the desired change in water quality. It is important when setting targets that realistic, achievable goals are put forward so that everybody can have confidence that the required status will be achieved.

Each objective will be set to achieve a previously-agreed use and may also incorporate a timetable for implementation. For example, the following objectives may be set for a low grade river which will, it has been decided, be a future source of potable water supply:

- that the river will only be suitable for abstraction of water for low-grade industrial use until 1 January 2005
- that the river water will be suitable for abstraction for treatment as drinking water from 1 January 2005

One important point to note, with regard to this objective setting exercise, is that it is perfectly possible that the river water quality in a particular stretch of river is far better than is necessary to meet the desired quality objectives. In this event, it is necessary to decide whether it is politically acceptable to allow the river water quality to degrade, thereby saving money which may be better spent improving water quality elsewhere.

3. Setting River Water Quality Standards

For each defined water quality objective, a series of water quality standards must be established. These standards will take the form of physical, chemical and microbiological limits on water quality which, if met, will ensure that the river water complies with its set objective. For example, rivers which have as an objective that they will be capable of supporting fish will have a low limit for the concentration of un-ionised ammonia as this chemical species is toxic to fish.

It is important, if the standards are to be set at a level which is neither too strict (which may inhibit development) nor too lax (which may prevent the water quality objective being met) that the agreed limits are based on the most up to date scientific evidence obtainable with, if necessary, a reasonable margin of error being included. Appropriate limits may thus be obtained from scientific literature on toxicity levels, if protection of plant or animal species is part of the quality objective, or from empirical evidence on the effects of water pollution on other water uses (eg, the effect of high concentrations of microbiological species in water used for irrigation of agricultural crops).

4 Setting Discharge Limits

Once the allowed concentrations of pollution parameters are established within each river reach it is a relatively simple matter, knowing the flow of a discharge, the flow of the river and the upstream concentration, to calculate the maximum concentration of any parameter which can be allowed within the discharge. This calculated value, plus any desired margin of error to allow for, for example, periods of low river flow, then becomes the discharge limit for this parameter. If a discharge contains many potentially polluting parameters, limits for each one should be put into the overall discharge permit for the effluent.

This method of pollution regulation has the advantage that, aside from any margins of error which may be allowed, only the agreed necessary pollution control will be enforced. Thus if, for whatever reason, a river has a 'low grade' objective (eg, that the water does not become objectionable or foul-smelling) then money is not wasted implementing unnecessary pollution control measures.

A further advantage of this quality objective system is that the maximum assimilative capacity of the receiving watercourse can be used as long as the previously designated water quality standard is not exceeded. Thus, a discharger positioned on an estuary, where dilution is large, is likely to be allowed to discharge a greater concentration of pollutant than a similar discharger on a small river. Although at first glance this seems unfair to the discharger on the small river, it does mean that pollution control is implemented as considered necessary, thus conserving resources.

One potential disadvantage of this pollution control method is the fact that, as referred to above, similar dischargers may be subjected to completely different discharge limits depending upon their location within river catchment areas. This situation, although optimised to the river quality objectives in each location, may be seen by the dischargers as anti-competitive as companies within the same industry may have widely varying pollution control expenditures which may, in turn, have an impact on the price of their goods or services.

3. Water Quality Planning in India

In India, while there are some very large rivers, there are many others which have only a meagre flow. Even in the case of large rivers, because of extraction of water for irrigation the flow is considerably reduced. This is particularly true during low flow season season and when the demand of water for agriculture is high. In many cases, because of impoundments and abstractions and also the seasonal nature of the river, the channel may be dry for 3 to 6 months in the year.

Further, water quality planning also has to take into account the fact that for a large fraction of rural population living on the banks of the river, the river water is the only source for domestic water requirements.

The utilisation of assimilative capacity of a river for waste disposal, which was discussed in the earlier section, is therefore not considered a viable approach in setting discharge limits. Under the Environment Pollution Control Act 1986, effluent standards have been set for different industries uniformly throughout the country. Only in cases when the effluent is disposed in the sea or estuary, location specific discharge limits may be allowed.

Most of the pollution of rivers in the country can be attributed to the discharge of untreated municipal wastes. In order to mitigate the problem, the following approach is adopted:

- Water quality surveys are carried out in river stretches to establish the existing water quality
- Surveys are also carried out to determine the existing and planned beneficial uses of the stream in different reaches, such as abstraction for drinking water supply, fish culture, organised religious bathing, etc
- The existing water quality in a river reach is then compared with the water quality standards for the beneficial use in the reach requiring the most stringent water quality
- Action plans are formulated where the existing water quality does not meet the required water quality

The Central Government (National River Conservation Directorate, Ministry of Environment & Forests) co-ordinates the pollution control programme identified under the action plan. In the case of municipalities, the Government also gives subsidy to create necessary infrastructure for pollution control measures. State Pollution Control Boards take action in regard to industries, which do not meet their waste discharge permit.

4. Water Quality Monitoring

Networks for water quality monitoring must conform to the objectives of the monitoring programme. A clear statement of the objectives is therefore necessary. This will ensure collection of all necessary data and avoid needless and wasteful expenditure in time, effort and money. Further, the data collected under the programme should be periodically evaluated to judge the extent to which the objectives were acheived. If necessray, the programme should be modified to fill in any gaps in the data or to take into account any change in the requirements of the programme.

The following definitions are suggested to classify the monitoring programmes in relation to their objectives:

Monitoring: Continuous, standardised measurement for any one or more of the following purposes

- to classify water resources and build up an overall picture of the aquatic environment
- to collect base-line data against which future changes can be assessed
- to detect trends in water quality changes

Surveillance: Continuous specific observations relative to control or management of the water resource

- to evaluate the suitability of water for a particular use
- to check for compliannce of permits for discharge of effluents in the waterbody

Surveys: A series of finite duration, intensive programmes designed to measure the water resouce in more detail for a specific purpose, such as

- to investigate pollution
- to collect sufficient data to perform in depth analysis of a particular phenomenon

To ensure that all necessary water quality information is collected systematically throughout, for example, a river catchment, it is customary to design a so-called ‘monitoring network’. Such a network would define the type (and therefore the objective) of each sample together with the number and location of each monitoring station (the ‘network density’), the water quality parameters to be measured and frequency of monitoring.

Table 1 shows the basis for the design of monitoring network which has been developed for Hydrology Project. The table gives sample type, objective, network density and sampling frequency for a range of different monitoring purposes.

Tables 2, 3 and 4 give water quality parameters which have been suggested for different categories of samples.

5. Data Interpretation

Once the analytical data is returned from the laboratory it needs to be analysed and interpreted. How this is done will depend upon the initial sample objective. For example, if a sample has been taken to identify a temporal trend it will need to be analysed in conjunction with other similar samples which have been taken from the same sampling point on previous occasions.

Although, due to the specific nature of sample data interpretation mentioned above, it is impossible to specify all methods of data analysis which might be required, a number of the most common techniques are discussed below.

Assessment of Trends

The simplest way of spotting trends in water quality data is to plot the data points on a so-called 'time series' graph. This is a graph where the 'x' axis is marked in units of time and the 'y' axis is normally in concentration (or sometimes load – see 'Calculation of Flux', below) of the physical, chemical or microbiological parameter being assessed. Once this graph is plotted, assuming it contains enough data points, obvious trends in the data are relatively easy to spot.

Other advantages of this type of presentation are:

- outlying data points are normally obvious
- many people find visually presented data more acceptable and more readily understandable

Time series graphs are also useful for spotting connections between two or more water quality variables. If it is suspected, for example, that the biochemical oxygen demand in a river reach increases when the suspended solids load increases, an effective way of checking this can be to plot both of these variables on a time series graph. Visual inspection can then be used to see if peaks and troughs for the two variables coincide.

It is important when presenting data graphically that:

- all graphs are easy to read and understand - in particular the temptation to put too many data sets onto one graph should be avoided; it is better to present this information using more than one graph if necessary
- the scale of the axes used is such that the data cover a large percentage of the graph
- all graphs are clearly titled and each axis, and if appropriate each data set, is clearly labelled

There are also a number of more advanced techniques which can be used to look for trends in water quality data. Although, a complete description of such techniques is outside the scope of this module, there follows below a brief outline of some of the methods available:

- statistical trend analysis - it is possible to analyse trends in data through the use of sophisticated statistical analyses; trend analysis can be important for the analysis of water quality data as it can aid understanding of the variability of data and also allow predictions to be made of likely future water quality. In addition, patterns 'hidden' in the data (eg, the data may vary seasonally) can also be statistically removed in order to better expose an underlying trend
- regression and correlation analysis - regression and correlation analysis are related techniques which are used to assess the association between two or more variables; both can be useful techniques for establishing the factors which regulate the variability of a particular water quality parameter

It is important to remember that the above techniques, whilst extremely powerful when used correctly, can lead to false conclusions and, therefore, poor management decisions if used by the inexperienced. It is often advisable, therefore, to use the simplest data analysis technique which will adequately perform the required task.

Calculation of Flux

Flux, the load (mass) of a substance passing a particular point over a given period of time, is calculated by multiplying the concentration of a substance, obtained from the analytical determination, by the flow of the watercourse. Thus, it is necessary to know the flow of the watercourse at the approximate time that the sample was taken, so some co-ordination of effort between sampler and flow measurement specialists is required.

As an example, consider a sample taken at a point in a river for which the BOD = 5 mg/l and the flow measured at the same point and at the same time = 5 m^3/s (cumecs):

$$\text{BOD} = 5 \text{ mg/l} = 5 \text{ g/m}^3$$

$$\text{Flow} = 5 \text{ m}^3\text{/s}$$

$$\text{Flux} = 5 \text{ g/m}^3 \text{ X } 5 \text{ m}^3\text{/s} = 25 \text{ g/s}$$

Note that flux is expressed as a load; that is a mass per unit time.

Compliance Assessment

If a sample of a watercourse is taken to see if it complies with its water quality objective the only data analysis which may be required is to numerically compare each parameter in the analysis with each relevant standard of the objective (although some permits have more complex conditions). Such an analysis would only give the compliance of this one particular sample, however. It may be more useful to report the percentage of such samples which have failed the objective within a specific time period as this may give some indication of the likelihood of future failures based upon past experience.

Similar arguments apply to effluent samples taken to assess the compliance of a discharge with its permit. In this case, however, the failure of one sample may become more important, particularly if the permit is a legal document the non-compliance with which may result in prosecution or fines for pollution.

Data Presentation

Finally, it is often the case that those who receive, and may need to act upon, water quality data are non-technical people. Often managers, politicians or members of the public need to comment or make decisions based upon water quality data. Unless such people are technically qualified, data alone will not of any use to them; they need to know what the data means.

There are a number of ways that water quality data can be made more meaningful to a non-technical audience including the following:

- comparing the data with national water quality standards - this gives an insight into the scale of a particular data set (e.g., if the data show that a particular groundwater sample contains a higher concentration of pollutant than is allowed by a national drinking water standard, most people would assume that it may not be safe to drink this water)
- comparing the data to international standards - it may be useful to compare the data to standards used by other countries (e.g., the United States) or international organisations (e.g., the World Health Organisation or the European Union) particularly if standards for a particular pollutant have not been defined nationally
- comparing the data derived from one area to data from another similar area - for example, it is easy to see how two similar rivers compare in terms of their pollution load when their water quality data are presented together
- showing how water quality has changed at one or more sampling points either over time or due to a particular event (e.g., the construction of a power station on a river reach)

Many of the above techniques are considerably enhanced if the data are presented graphically. However, care should be taken to ensure that the graph type is chosen to clearly transmit the necessary information (see above).

Table 1
Water Quality Monitoring Objectives, Network Densities and Sampling Frequencies

Category	Type	Objective	Network Density	Sampling Frequency (per year)	Parameters
Monitoring[1]	Baseline	Natural background concentrations	One for each mainstream stem and one for each major tributary (>20% of flow at confluence)	Initially 3 - 4 X then repeat every 2 - 3 years	see Table 2
	Trend	Detection of changes over time due to anthropogenic influences	*Mainstream:* - after each 1½ -2 days travel time or after each major infiltration (whichever is sooner) *Tributary:* Before confluence if >20% of mainstream flow	12 X (if river catchment area > 100,000 km^2) 24 X (if river catchment area < 100,000 km^2)	
	Flux	Calculation of load Calculation of mass flux	State or border crossings Outflows into lakes and seas and oceans	Simultaneously with flow measurement (ie, 24 X)	
Surveillance[2]	Water Use	Check that water is fit for use	At all points of use or intake	see Section 2.1, 'Water Use'	see Table 3
	Pollution Control	Check effects of discharges Check water quality standards	Upstream and downstream of discharge point In river after mixing	For discharges with significant effects: 12 X (or 52 X for high significance). Annually for others. For river waters: 12 X	
Survey[3]	Classification	Classification of reach	Within each reach	Annually (less frequently if reach unchanged, more frequently if considerable changes)	see Table 4
	Management and Research	Investigation of pollution and need for corrective measures Special Interest Filling in knowledge gaps	Dependent upon scale of survey required	Sufficient to characterise problem and likely solution	

[1] Monitoring: Long-term, standardised measurement in order to define status and trends
[2] Surveillance: Continuous, specific measurement for the purpose of water quality management and operational activities
[3] Survey: A finite duration, intensive programme to measure for a specific purpose