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MIXING OF CHEMICAL SUBSTANCES IN RIVERS WITH REFERENCE TO OKANAGAN RIVER AT PENTICTON

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BACKGROUND

1. Introduction

The mechanisms which produce natural mixing in rivers are an important part of the overall transport process for waterborn substances, and therefore of river ecology. For this reason, a thorough understanding of natural mixing processes in rivers is essential to sound management of the water environment.

Some of the substances may be undergoing degradation or conversion to other chemical and physical forms through various chemical, biological and physical processes. The rates at which these processes occur in a certain parcel of water are influenced by factors such as temperature, dissolved oxygen concentration, biochemical oxygen demand, and the concentration of various other chemical constituents. Turbulent and secondary currents are continually at work mixing each parcel of water with its neighbours, smoothing out any differences in the water quality which exist within the stream cross section. The mixing processes are slow, particularly in large rivers.

2. Conservative Substances

Chemical constituents of water which undergo no process other than dilution are called conservative substances. They are unaffected by processes such as decay, chemical reactions, transformation to a different form, and production or removal by sources or sinks. However, it is also necessary to specify that the fluid properties (e.g. density, viscosity, surface tension for fluids, and density and particle size for suspended solids) of conservative substance are identical to those of the ambient river water.

2.1 Convection and diffusion characteristics

In the attempt to characterize dispersion process in a turbulent open channel the following terms are considered: (a) concentration by weight of dispersing substance, distance coordinates in longitudinal, vertical and lateral directions; local velocity of flow in these (x, y and z) directions, (b) coefficients for local turbulent mass transfer in the three directions (x, y and z). The terms in the groups (a) are called the convective transport terms and the terms in the group (b) are called the diffusion terms.

The characteristics of a conservative substance is that there can be no transport of the substance across either the wetted perimeter or the water surface by either convection to water sediment or water air interfaces or diffusion.

3. Non-Conservative Substances

If the dispersing chemical constituents of water undergo changes so that there is either production or removal due to chemical reactions, change of state, or transfer across the boundaries, the constituents, are called non-conservative substances. In this case appropriate source or sink terms must be considered in addition to the convective transport terms. Collectively, depending on the nature of phenomenon, these terms can assume a variety of functional forms, all of which represent a rate of addition or removal of the dispersing substance at the point in space and time for which the evaluation of dispersion is made. If the physical properties of the dispersing substance differ from those of the ambient water it must be recalled that the velocities in the three directions (x, y and z) and the diffusion coefficients represent the motion of the dispersing substance, which is no longer necessarily the same as that of the transporting fluid.

Dissolved oxygen, biochemical oxygen demand, and heat are common examples of non-conservative quantities; radionuclides represent a decaying substance; and suspended sediment and materials that are adsorbed thereon are examples of substances which may have different transport properties.

4. Dispersion in Open Channel Flow

The study of the dispersion process in open channels has become very astute with the introduction of readioactive waste, pesticides, herbicides and preservatives, such as pentachlorphenate (PCP). Many of these substances (a) are assigned a tolerance level for aquatic biota and other water uses, several orders of magnitude lower than that for most other pollutants, (b) are chemically very stable and retain their toxicity for long periods of time before yielding to natural decay process, and (c) cannot be removed by conventional water-treatment practices.

Contaminants are transported and dispersed in open channel flow in various forms, such as: (a) dissolved matter, (b) adsorbed by suspended sediment particles, and (c) attached to bed material load.

Dissolved contaminants are transported at the mean velocity of the stream and are dispersed by the mechanism of turbulent diffusion and by the differential convection currents associated with velocity gradients. Contaminants that are transported as fine particles in suspension disperse in the same manner as dissolved contaminants and at essentially the same rate.

On the other hand, contaminants which are transported as part of the bed-material load move in a sequence of steps of random length between which particles may remain buried for considerable periods.

The factors that are invariably associated with transport and dispersion processes of dissolved and suspended particulate matter are turbulence, velocity gradients in vertical and horizontal directions, and secondary flows originating from beds or obstructions.

The processes by which dissolved and suspended particulate matter is dispersed in open channel has been subjected to theoretical analysis in recent years. In 1976, Water Quality Branch, IWD, was engaged in the study of dispersion of dissolved nutrients and their transport by Okanagan River to Skaha Lake. In this study, presented here, the dispersion pattern of ammonia, observed in the Okanagan River at Penticton, is demonstrated.

OKANAGAN RIVER CHANNEL

1. Introduction

The reach of Okanagan River at Penticton, B.C. is man-made channel connecting Okanagan and Skaha Lakes. Chemistry of water in the channel is affected by pollutant inputs from the Penticton municipal outfall, Okanagan Lake, agricultural and urban run-off via Shingle and Ellis Creeks and seepage of groundwater and riparian water from backswamp areas drained by the meanders of the old stream. All these variables pollutant sources, integrated in the reach of Okanagan River, significantly affect spatial and temporal changes of pollutant transport in this channel. Because this channel is not large, characterized by a small number of tributaries and has no bends or large obstructions on the beds, pollutants are dispersed at rates that are less than the dispersion rates in large natural rivers characterized by all these factors influential in dispersion processes.

Objective of this short-term study was to examine lateral, vertical and longitudinal variation of nutrient concentration and to determine precision of their transport estimation in the channel. In order to meet this objective simultaneous sampling for chemical analysis were conducted in combination with hydrometric measurements in fine selected channel cross sections on December 9 and 10, 1976.

2. Measurements

Each channel cross section was divided into a minimum of twenty subsections for the purpose of hydrometric measurements and four slices for simultaneous chemical sampling. The geometry and shape of the cross section flow velocity at various points were obtained by the usual stream gauging technique for discharge measurements. Beginning at the left bank, depth and point velocity measurements were taken at 0.2 and 0.8 of the water depth at each of twenty vertical subsections across the stream. These data were used for determination of mean velocities of flow, drawing isovels and calculation of discharge within the subsection and in the channel cross section. Chemical slices were divided into the upper and lower stratum. The sampling points, called slice elements, were located in the middle of each slice and stratum, approximately at the same depth as velocity measurements. Sets of three replicate samples were collected simultaneously by the means of a replicate sampler at the slice-element of the upper stratum. In the lower stratum, a sampling pump was applied in rapid sequence over a one-minute period to approximate true simultaneous sampling.

3. Results

3.1 Discharge

The diagram showing lines of constant velocity of flow indicated that the flow was symmetrical at Station 1 (Below Okanagan Lake dam) and approximately symmetrical at Station 5 (Near the Penticton airport). On the other hand, at Station 2 (below Penticton municipal outfall) velocity distribution was asymmetrical. The asymmetry in distribution of both the discharge and velocity was further evident at Station 3 (below Shingle Creek) and Station 4 (below Ellis Creek).

This asymmetry in channel flow reduces the accuracy of discharge determination for the following reasons: (a) an error in the determination of one sub-section discharge has a disproportional effect on the accuracy of the total discharge determination and (b) asymmetry of flow commonly indicates presence of meandering thalweg (line of maximum depth of flow) and this in turn indicates cross-sectional instability. Some improvement in accuracy of flow determination could be achieved by reducing the size of the sub-sections in the region of high discharge.

The observations obtained in this Okanagan River reach imply that Stations 2, 3 and 4 would not be suitable for long-term hydrologic monitoring. At Station 5, however, to confirm the approximately symmetrical discharge pattern, further measurements will be required during a greater range of flows.

During two day of sampling, the discharge of 26.75 $m^3 s^{-1}$ regulated by the dam located below Okanagan Lake remained constant at Station 1 (below Okanagan Lake dam). Along the river channel the discharge increased to 28.67 $m^3 s^{-1}$ at Station 5 (near the Penticton Airport). This 7 percent increase, resulting from the contribution of the Penticton waste treatment plant, Shingle Creek and Ellis Creek, indicates a small contribution from the tributaries towards improving dispersion of chemical substances in the channel. A similar flow require during several months, illustrated by hydrographs, is a characteristic feature of this river system.

3.2 Ammonia

The behaviour of ammonia concentration in the channel is characterized by the steep lateral gradients across the channel, particularly at the station located below the municipal outfall. On December 10, there was an increase in mean ammonia concentration from 0.0007 mg l^{-1} at Station 1 to 0.22 mg l^{-1} at Station 2, with maximum of 0.615 mg l^{-1} observed at the left bank of Station 2.

The mean concentrations of ammonia were still high at all stations located downstream, but at Station 5 the lateral concentration gradient in the channel cross-section was markedly reduced.

Ammonia loads below the Penticton municipal outfall were high and remained high at Station 5. The net increase in ammonia load between Stations 1 and 5 ranged from approximately 1,620 to 2,620 percent. It would be reasonable to conclude that much of the measured ammonia load reaches Skaha Lake. The observation that there is a decrease of ammonia load at individual stations along the Okanagan River reach can be ascribed to the effect of a variety of mechanisms, such as oxidation and association of ammonia with particulates.

The steep lateral gradients, indicated by concentration data, also were observed with the partial load data determined for each channel cross section.

3.3 Pentachlorphenate

There is no specific information on the behaviour of pentachlorphenate (PCP) in a river channel such as the reach of the Okanagan River at Penticton, B.C. However, the behavious of ammonia as a dissolved substance and, particularly, its lack in mixing can approximate dispersion pattern of another soluble substance such as PCP.

SUMMARY

1. General

Theoretically, dispersion of a plume of dissolved, non-conservative chemical substances from point sources in natural stream waters may be considered as two processess: (a) the convective process in which the movement of substanes is dependent on their initial convective velocities in longitudinal, vertical and lateral directions; and (b) the diffusive processes in which spreading of chemical substances in defined by the mean flow velocity and the dispersion coefficients.

2. Okanagan River at Penticton, B.C.

A simplified and direct method for measuring dispersion of dissolved nutrients was used during the study in the Okanagan River at Penticton, B.C. on December 9 and 10, 1976. A specific aspect of this study, the variation of ammonia concentration and transport at selected cross-sections of the river channel is relevant to the question of the mixing of other soluble materials such as pentachlorphenates.

3. Ammonia

The measurements of ammonia concentration revealed the existence of significant lateral concentration gradients in five channel cross sections located below major input sources of nutrients. A very steep lateral gradient of ammonia concentration was observed particularly below the outfall from the Penticton waste treatment plant. The discharge outlet from the plant is located on the left (east) bank of the river channel. The lateral variation of ammonia concentration was ranging from 0137 - 0.615 mg l^{-1}, observed at the left bank, to 0.008 - 0.027 mg l^{-1}, observed at the right bank.

At station located below Shingle Creek concentration of ammonia varied from a range of 0.228 - 0.328 mg l^{-1} at the left bank to 0.014 - 0.028 mg l^{-1} at the right bank. The large lateral gradient of ammonia concentration persisted further downstream at station below Ellis Creek. At the cross section located near the Penticton airport, there was still significant concentration ranging from 0.165 - 0.184 mg l^{-1}, observed at the left bank, to 0.046 - 0.056 mg l^{-1} at the right bank of the channel.

In terms of cross-sectional means, there was a pronounced longitudinal variation of ammonia concentration along the river channel. The range of cross sectional means of ammonia concentration at the cross section above the outfall was 0.004 - 0.007 mg l^{-1} and the range below the outfall was 0.127 - 0.218 mg l^{-1}. At station below Shingle the cross-sectional mean concentration of ammonia was in the range of 0.106 - 0.135 mg l^{-1} and then there was no significant downstream decline at stations below Ellis Creek and near the Penticton airport.

CONCLUSION

The steep lateral gradients of ammonia concentration observed in the five channel cross sections provide the evidence that a considerably higher river reach would be required to achieve complete mixing of ammonia. In terms of ammonia loads, the increase between the station above the Penticton outfall and station located near the airport was in the range of, approximately, 1,620 - 2,600 percent. It is reasonable to assume that much of the measured ammonia load reaches Skaha Lake.

With reference to the pentachlorphenate (PCP), this dissolved substance could undergo a variety of changes along the investigated river channel. These changes could include hydrolysis, degradation and adsorption on particulate matter. It has not, however, been established to what degree PCP would adsorb on sediment particles in this system. If it is strongly adsorbed to the silt and fine-sand-size rnage of particles they may travel for long distances in suspension. Suspended particles, than have a tendency to settle and eventualy be deposited on bed, where they behave as bed material particles until they can be reentrained in the stream flow. Nevertheless, suspended sediment is unlikely to be dispersed to a greated degree than soluble material.