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Literature and information review of groundwater input of nutrients and toxicants to Port Phillip Bay

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Summary

As part of the Port Phillip Bay Environmental Study, a review has been made of contaminant discharge to Port Phillip Bay.

No hydrogeological and hydrochemical investigations have been conducted and no reports have been written on the nutrient and toxicant input by groundwater flow into Port Phillip Bay. The Werribee Treatment Complex reports are an exception.

Most available reports used for the review of groundwater discharge rates and nutrient and toxicant inputs into the Bay have been compiled during the 1980's and are outdated.

The Rural Water Commission is currently conducting a groundwater pollution monitoring program west of Melbourne

The estimate for groundwater discharge into the Bay is $5.5x10^7$ m^3 y^{-1}. This does not include groundwater input to the Bay's Central Zone by point and diffuse discharge, nor the discharge into Corio Bay or discharge from aquifers of the Bellarine Peninsula. Therefore the actual discharge flux into the Bay would exceed the available estimates.

By taking the difference between assumed aquifer recharge rates and discharge rates for the western industrial areas of Melbourne, the contribution of baseflow to rivers has been estimated at 80% of the total groundwater flow of the aquifer. Thus, baseflow is an important discharge component of streams and rivers. However, no direct measurements and calculations have been made to quantify the baseflow component to individual surface water bodies. The relationship between pollution source, groundwater flow system and effluent streams has to be determined. It is irresponsible not to consider baseflow as a potential source of stream and river contamination.

Highly contaminated rivers are located west and south-east of Melbourne City, near the Werribee Treatment Complex and at Geelong.

The hydraulic connectivity of principal aquifers is not well understood. Pollutants are transported cross-formationally between aquifers. The utilization of hydrogeological cross sections parallel to the regional groundwater flow direction to the Bay is recommended for the study of pollution zones west and south-east of Melbourne and Corio Bay.

Aquifer contamination in the Port Phillip region is serious and widespread. Discharge zones of nutrients and toxicants by groundwater flow to the Bay have been identified and include the Werribee-Altona, Port Melbourne, South-eastern and Corio Bay Zones and the Bellarine and Nepean Peninsulas (Table 1).

The total groundwater nutrient load to Port Phillip Bay from the Werribee Treatment Complex is 34 t y^{-1} N and 8.1 t y^{-1} P. From the Nepean Peninsula about 1.2×10^2 t y^{-1} NO_3 is discharged into the Bay. However, fundamental chemical data to quantify the pollutant input from other zones into the Bay are lacking. Of particular concern are the Corio Bay and South-eastern Zones.

Heat input to the Bay by forced-convective heat flow has not been investigated, but higher geothermal gradients (7ºC/100m) occur in the Central Zone of the Bay and on the Nepean Peninsula.

Background

The Port Phillip Bay Environmental Study aims to determine the environmental status of Port Phillip Bay in relation to nutrients and toxicants and to provide a basis for the long-term management of point-source and diffuse inputs.

CSIRO is managing the Study on behalf of a Management Committee of Victorian agencies (Melbourne Water, Department of Conservation and Natural Resources, Environmental Protection Authority and Port of Melbourne Authority).

The design of the Study has been developed to identify the range of research tasks necessary for the evaluation of physical processes, nutrients, toxicants and ecology of the Bay and relevant inputs (CSIRO, 1992). These tasks describe the scientific information required to achieve the Study objectives. However, some tasks may not be required to be implemented in their entirety because sufficient valid information already exists.

The Management Group commissioned a series of literature and information reviews on issues relevant to the study objectives and Port Phillip Bay.

A key task element is groundwater inputs to the Bay.

Terms of Reference

The terms of reference for this study specified two primary objectives:

1. *To provide a critical review of available literature on the physical and chemical groundwater input to Port Phillip Bay, to be used later to refine the relevant tasks in the Port Phillip Bay Environmental Study Project Design (CSIRO, 1992).*

2. *To provide hardcopies of all documents cited in the above literature review.*

This literature review provides a significant resource document for the following three tasks described in the Port Phillip Bay Study Design (CSIRO, 1992):

- Task N1.4: Nutrient inputs (carbon, nitrogen and phosphorus) by groundwater to Port Phillip Bay (PPB).

- Task P6: Physical inputs (water, salt and heat) by groundwater flow to PPB

- Task T4: Toxicant inputs (inorganic and organic) by groundwater to PPB.

1.0 Introduction

The term groundwater refers to all the subsurface water that occurs within the watertable in fully saturated soils and geologic formations. Topography-driven, cross-formational groundwater flow is an integral part of the hydrologic cycle in the Port Phillip Bay region as well as a transportation link between the source and destination of inorganic and organic contaminants as well as heat. The main mechanism by which groundwater can be polluted is by leaching and/or infiltration of contaminants from landfills, dumps, sewage treatment plants, septic tanks, agricultural activities, urban development and industrial sites. By advection and dispersion pollutants migrate down gradient and, as baseflow, enter surface waterways and/or discharge into the Bay. Attenuation processes in the unsaturated and saturated zone tend to naturally "filter" the contaminated groundwater. However, the hydrogeological environment does not attentuate all pollutants to the same degree and its capacity to assimilate pollutants is limited.

2.0 The Port Phillip Region

The Port Phillip Region is the drainage catchment of Port Phillip Bay, constituting an area of about 9,800 km^2. The climate of the region is temperate. The Bay is surrounded by land of low topography; the highest elevation of 1200 m AHD is in the NE part of the region. All major streams and rivers (e.g. Yarra, Maribyrnong, Werribee) drain to the Bay - the largest, the Yarra River, flows through the city of Melbourne and drains about 52% of the Port Phillip Bay catchment (Leonard, 1979).

Port Phillip Bay is a large, shallow, marine embayment with a surface area of approximately 1950 km^2. About half of its area is less than 14 m deep with the central part of the Bay having a maximum depth of 22 metres. Port Phillip Bay is an almost landlocked body of tidal salt water, and water exchange with the open ocean is limited owing in part to the narrow connection with Bass Strait. The Bay provides for an array of port, industrial and recreational usage.

The population and industrial development of Victoria is concentrated within the Port Phillip Region. Sixty percent of the land is used for agriculture, 12% for residential areas and about 1% of the land is utilized by industry. Industrial complexes are concentrated in the western and south-eastern areas of Melbourne and near Geelong at Corio Bay. Future residential and industrial development are mainly in areas of Melbourne and Geelong (Neilson Assoc., 1987).

3.0 Geology

A comprehensive outline of the tectonic setting and geology of the region is given by Leonard (1979).

The geological sequence consists of two principal divisions: basal sedimentary formations of folded and fractured Palaeozoic sediments and igneous intrusives which are partly covered by Cainozoic sediments and igneous extrusives of varying thickness and areal distribution. Beneath the Nepean Peninsula the Cainozoic sequence attains a maximum thickness of 1000 m due to synsedimentary faulting. Elsewhere in the on-shore Port Phillip Basin its thickness is mostly less than 250 m. The principal Cainozoic formations and their lithological and hydrogeological characteristics are listed in Leonard (1992).

4.0 Hydrogeology

Leonard (1979, 1992) describes the hydrogeology and on-shore hydrostratigraphy of the Port Phillip Region in detail (including isopach and distribution maps of the on-shore principal Tertiary aquifers).

The inferred dimensions and parameters of the aquifers were obtained by hydrostratigraphic analysis (of all boreholes drilled in the Study Region) held by the Department of Industry, Technology and Resources (now named the Department of Manufacturing and Industry Development, DMID). The Department of Water Resources, Victoria, the Rural Water Commission and Melbourne Water (whose data-base is managed by Coffey Partners International, Melbourne) have their own hydrogeological data bases.

Hydraulic parameter data of the main aquifers (transmissivity, hydraulic conductivity and storativity data) are limited and localized. Except for the Newer Volcanics aquifer west of Melbourne which has been intensively investigated (Riha and Kenley, 1978), only a small number of aquifer tests have been conducted in the Port Phillip Region (Leonard, 1979). Most of the pumping tests were designed to test the more permeable horizons in the aquifer system and thus the hydraulic values do not generally represent a regional characterization of the aquifer system. Therefore the range of values given in Leonard (1992) should be regarded as indicative only.

On-shore, the aquifers underlie most of the Port Phillip Region at depths ranging from several hundred metres to less than one metre. No drilling of deep formations or seismic survey has been conducted off-shore in the Bay itself. Therefore, the hydrostratigraphy, aquifer thicknesses and areal distribution of the aquifer units under the Bay are not known.

Water-bearing formations occur in most of the geological units. They include the basement Palaeozoic and Mesozoic sedimentary and igneous rocks, the sand and gravel of the Werribee Formation, the Fyansford (Newport) Formation, the Brighton Group and its equivalents, the limestones and calcarenites of the Batesford Limestone and the Bridgewater Formation, and the fractured and weathered basalts of the Older and Newer Volcanics.

Recommendation: The geometry, lithology and tectonic strain of the hydrostratigraphic units, and the evidence from hydraulic head and hydrochemical data, suggest that the aquifers are hydraulically connected, at least on a local scale. This is of importance to any contaminant groundwater study. No regional study has been conducted in the Port Phillip Region to evaluate the hydraulic interconnectivity of aquifers nor to analyse the cross-formational groundwater flow pattern. The construction of regional hydrogeologic cross sections parallel to the regional groundwater flow direction (to the Bay) and potentiometric contour maps for different depth ranges are suggested to analyze groundwater flow patterns. Another simple procedure to determine upward or downward groundwater flow is to plot a diagram of pressure heads vs. depths for all hydrostratigraphic units. Points plotted above the hydrostatic pressure gradient indicate upward flow; points below the gradient show downward flow.

5.0 Waste Disposal

Many waste disposal sites are scattered throughout the Port Phillip Region. Traditionally solid waste was disposed of as landfill in disused quarries, on land reserved for munipical dumps and on land with low economic productivity (eg. swamps, wetlands). Waste disposal site locations are listed in Leonard (1992) and presented in diagram 5 in Neilson Associates (1987).

Disused sand pits in the Brighton Group south-east of Melbourne, clay pits and valley fills in the basement rocks to the east, and the open basalt quarries in the Newer

Volcanics west of Melbourne account for the majority of sites, both past and present (Leonard, 1992, Chapter 8).

Liquid waste from domestic and industrial sources are currently treated at the Werribee Treatment Complex west of Melbourne and the South-Eastern Purification Plant (SEPP) south-east of Melbourne. Seepage from septic tanks in unsewered residential areas also contributes to ground and surface water pollution.

Data records on the direct usage of the groundwater system for the disposal of waste and groundwater contamination can be obtained from the EPA, the Department of Health and DMID. The data were compiled and collated in the early 1980's and the records have not been kept current.

5.1 Municipal Wastes

Municipal wastes consist primarily of solids and include domestic garbage, residential garden refuse, building materials and household items.

Information on past municipal disposal sites from the Health Department and EPA are incomplete, especially data before 1973. However, the location of the sites generally reflect the distribution of residential areas.

The aquifers affected by the disposal of municipal wastes have been mostly within the Brighton Group in the south-eastern suburbs, and in the Newer Volcanics north and west of Melbourne. To a lesser extent aquifers in the basement rocks east of the Yarra River have been affected. Several sites are located near the Bay at Altona-Brooklyn-Newport, in the south-eastern suburban region and at Geelong (Table 8.2, Leonard, 1992).

5.2 Industrial Wastes

Industrial wastes include greasy and dirty water, solvents and chemicals, organic and inorganic sludges, and liquids polluted with heavy metals such as chromium, lead, mercury and arsenic.

Before 1973 the disposal of industrial waste was not controlled. As a result reliable data on industrial waste disposal prior to 1973 are not available. Disposal sites have been licensed by the EPA since 1973 (Leonard, 1992).

The introduction of licensing provided a record of the type of site, the underlying aquifers and the major waste components. Large processing industries tended to operate their own disposal facilities which were mostly situated on land adjacent to the industrial plant. About 80% of industrial wastes generated which were not licensed for on-site disposal were disposed to the Tullamarine Tip Waste Disposal Site. Most of the remainder went to the Sunshine Municipal Tip until 1986.

Of those sites which were in operation at some time since 1973, 60% are in or on Newer Volcanic basalts in the industrial areas to the west of Melbourne - an area which contains the most polluted groundwater in the Port Phillip Region. Several former industrial waste disposal sites are located between 1 and 4 km from Port Phillip Bay (Leonard, 1992, Neilson Associates, 1987). At Altona and Brooklyn - west of Melbourne City (Newer Volcanics) - quarries, above-ground ponds and pits were used for disposal. The type of waste disposed contained heavy metals, oil sludges and phenolic liquids, acids, asbestos and nitrates. There is no information available of former near-coast waste disposal sites east and south of Geelong at Corio Bay.

At present six specially engineered landfills are licensed to accept industrial waste (Table 8.3, Leonard, 1992; Diagram 5, Neilson Associates, 1987). The Tullamarine Tip receives most of Melbournes liquid industrial wastes (Shugg, 1981); about 7 ML/month since 1971.

5.3 Sewage Effluents

A common type of on-site domestic sewage treatment plant in the Port Phillip Region has been the septic tank. Discharge rates from septic tanks generally range between 150 and 200 litres/person/day. The waste effluent is a major source of nitrogen and phosphorus in groundwater. Currently the density of septic tanks on the Nepean Peninsula is high. Parts of the south-eastern suburbs of Melbourne and the municipality of Frankston (near the Bay) also have high concentrations of septic tanks.

The main regional sewage treatment plant is the Werribee Treatment Complex (WTC) located 35 km southwest of Melbourne. It is underlain by the highly conductive Werribee Delta Formation and the Newer Volcanics basalts. It receives about 60% of the sewage output from the Melbourne metropolitan area. Of the daily load of 440 ML of raw sewage, oxidation and settlement lagoons treat about 44% of the volume with lesser quantities treated using grass filtration (26%) and land irrigation areas (30%). The treated effluent waters are discharged into the Bay *via* four outlets. About 4000 t y^{-1} of nitrogen and 1200 t y^{-1} of phosphorus are discharged into the Bay from the WTC.

The lagoons occupy 75% of the low lying coastal margin of the Complex and have a shoreline length of 20 km along Port Phillip Bay (Anderson, 1988b; Coffey Partners International, 1992).

6.0 Groundwater Flow and Pollutant Inputs to Port Phillip Bay

Groundwaters discharge into Port Phillip Bay either indirectly as baseflow *via* surface water bodies (e.g. streams, wetlands), directly from sub-marine zones, or as point sources. The regional groundwater flow direction is from the topographically higher regions of the Port Phillip Region catchments into the Bay (Leonard, 1979). However, local systems may exist with different groundwater flow directions. En route, the groundwater can be contaminated by waste disposal operations, septic tank seepages, agricultural practices, spillages and leakages. Pollution is most likely to occur in shallow unconfined aquifers which discharge into streams or into the shallow near-shore waters of the Bay.

6.1 Groundwater Discharge

Leonard (1979, 1992) approximates the average discharge rates of the principal unconfined and confined aquifers by the cross section method based on Darcy's Law: $\boldsymbol{Q = TiW}$, where $\boldsymbol{Q}$ is the discharge rate (m^3d^{-1}), $\boldsymbol{i}$ is the hydraulic gradient (mm^{-1}), $\boldsymbol{T}$ is the transmissivity (m^2d^{-1}) and $\boldsymbol{W}$ is the width of the discharge segment (m).

The applied method should be considered as an estimate of discharge rates only. Also, single transmissivity values have been used to characterize the conductivity on a regional scale. The hydraulic gradients are taken from iso-potential maps of principal aquifers (Leonard, 1979). On a regional scale the hydraulic heads and gradients are assumed to be uniform. Consequently, the flow per unit area is also assumed to be uniform and equal to the mean of flow through cross-sectional areas on a microscopic scale.

6.2 Groundwater Pollution Monitoring

The EPA has compiled a register of sites with known, or suspected soil contaminations. The register only shows sites with polluted soils. It should be emphasized that shallow groundwater has also been contaminated by leachates. The register currently contains information on 48 sites in the Port Phillip Region. Many more sites are contaminated but not yet recorded.

Monitoring wells were mostly drilled in the near vicinity of the inland waste disposal sites and leachate points. No wells monitor directly the input of pollutants into the Bay. With the exception of the Werribee and Altona Zone (Figure 1) the wells are too far away from the shore-line to make any meaningful assessment of possible inputs by nutrients and toxicants into the Bay.

Detailed investigations of groundwater contamination have been conducted by the EPA and DMID only for the basalt aquifer west of Melbourne (Anderson, 1988b; Coffey Partners International, 1992; Leonard, 1992; Riha and Kenley, 1978; Shugg, 1987a, 1989a; Stewart, 1988; Walker, 1990) and for the Fyansford-Brighton Group in the south-eastern suburbs (Hancock and Phillips, 1992; Leonard, 1992).

Samples of groundwater were analyzed for all major ions, TDS, pH, dissolved oxygen, phenolic compounds, surfactants and heavy metals (Pb, Cu, Zn, Cd, Cr, As, Cn). The concentration of organics were analyzed for some sites at Port Melbourne (Richardson and Waid, 1979; Shugg, 1987a).

6.3 Discharge and Pollution Zones

Based on inflow estimates from the principal aquifers and differences in pollution loading of the discharging water arising from various land uses, aquifer types and waste disposal practices, the near-shore areas of Port Phillip Bay are sub-divided into different zones (Leonard, 1979). The division by Leonard (1979) can be refined according to additional groundwater data and hydrochemical analyses (Coffey Partners International, 1992; Hancock and Phillips, 1992; Leonard, 1992; Richardson and Waid, 1979; Riha and Kenley, 1978; Shugg, 1981, 1985, 1987a, 1987b, 1989a, 1989b; Walker, 1990). The boundaries of the zones are not distinct (Figures 1 and 2, Table 1).

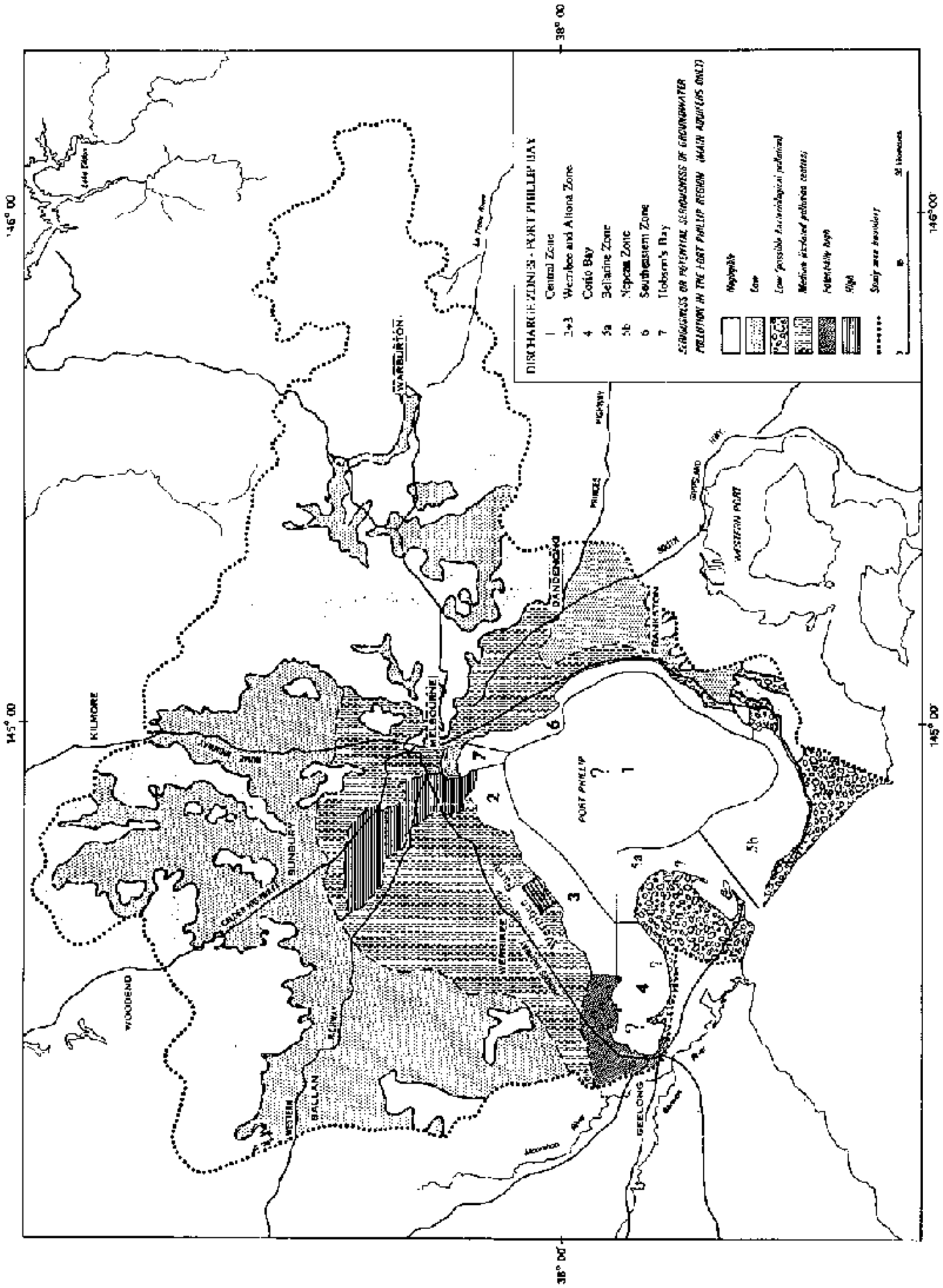

Fig. 1. Pollution & Discharge Zones in Port Phillip Bay (modified after Leonard, 1979)

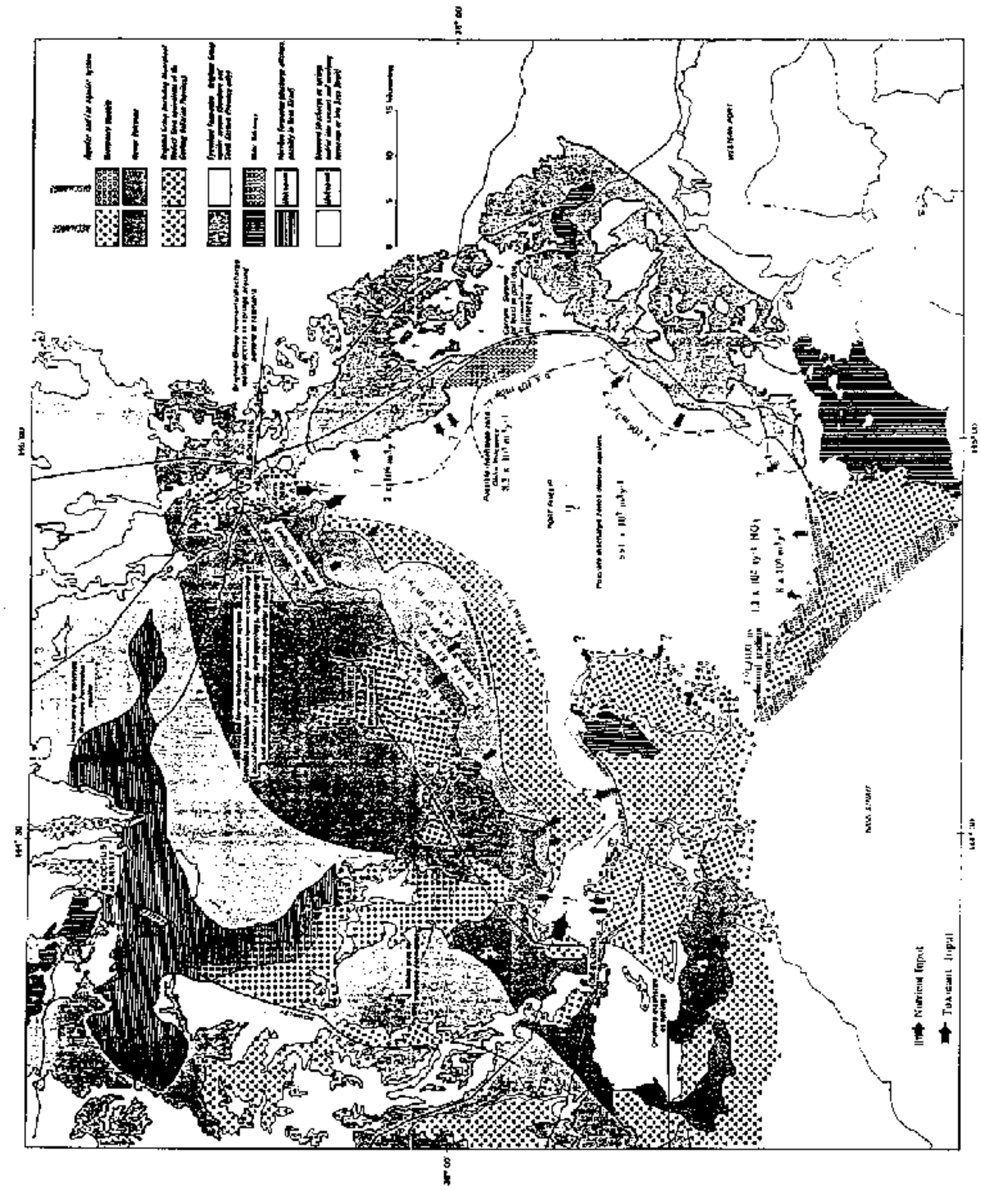

Fig. 2:Recharge and Discharge Zones and Nutrient & Toxicant Inputs into Port Phillip Bay (modified after Leonard, 1979)

Table 1. Groundwater discharge rates, nutrient and toxicant inputs into Port Phillip Bay for selected Discharge Zones and hydrogeologic units (see also Figures 1 and 2).

Discharge Zone	Aquifer System	Discharge Width km	Discharge Rate m^3y^{-1}	Nutrients	Toxicants	Heat $^oC/100$ m	Salinity mg l^{-1}TDS	References
Central	Older Volcanics Werribee F.		? $1x10^7$ to Bay and Bass Strait?	? likely	? likely	very likely very likely	? ?	Leonard'92
Werribee and Altona	Brighton F. Newer Volcanics	40 60	$5.6x10^5$ $4x10^6$?	possible N, P, C	possible phenols, PCB PAH, heavy metals	no no	2500-8000 1000-14000 $2.9x10^2$ ty^{-1}	Leonard '79,'92 Riha & Ken.'78 Shugg '78
Altona	Newer Volcanics	20 15	$1.6x10^7$ $1.3x10^7$ Riha et al. '78	N, P, C	phenols, PCB PAH, heavy metals	no	1000-14000 $2.9x10^2$ ty^{-1}	Anderson '88 Leonard '79,'92 Riha & Ken. '78 Shugg '81,'92 Stephan '81 Stewart '88
Werribee	Werribee Delta	19	$2.6x10^6$	34 ty^{-1} N 8.1 ty^{-1}P	heavy metals conc. is low	no	2500-8000	Anderson '89 Coffey '92 Stewart '88
Corio Bay	Bridgewater G.	?	?	very likely	very likely	no	2000-10000	Leonard '79,'92
Bellarine	Bridgewater G	?	?	very likely	possible	no	2500-8000	Leonard '79,'92
Nepean	Werribee F. Brighton F.	? 22	? $8x10^6$	N, P 1.2 ty^{-1} NO3	low	7 no	? 300-2000	Shugg 85, '87, '89
Southeastern	Older Volcanics Fyansford F. - Brighton G.	10.5 44	$8.2x10^5$ $3.6x10^6$	? yes, but no data	? possible phenols, heavy metals	no no	? 110-7000	Leonard '79 Walker '90
Hobson Bay	Port Melbourne Sd.	?	?		phenols, PCB,PAH, tars, oils, heavy metals (Pb, Hg)	no	2000-40000	Shugg '87,'89

6.3.1 Central Zone

The boundary of the Central Zone has been arbitarily drawn (Leonard, 1979). It corresponds approximately to the 13 m depth contour of the Bay. The hydrogeology and hydrostratigraphy under the Bay is not known. Diffuse discharge from deeper underlying formations or point source discharge *via* conductive fault systems is likely to occur under the Bay and to Bass Strait. Groundwater in the Werribee Formation does not discharge near the coast. Leonard (1979) estimates that about 1×10^7 m^3y^{-1} of groundwater flows through this principal aquifer and discharges in the Central Zone and Bass Strait. The input of nutrients and toxicants is also not known but it is assumed to be insignificant (Leonard, 1992).

Of importance, but not investigated, might be the input of heat into the Central Zone of the Bay. Heat is transported by groundwater flow (forced-convective heat flow). The geothermal gradient steepens in discharge areas where groundwater ascends from deeper aquifers to shallower depths. In a graben-type geological environment like Port Phillip Bay, the fault-severed aquifers enhance cross-formational groundwater flow and heat transfer. It is likely that geothermal anomalies and heat input into the Bay occur. Water surface temperature mapping by thermal infra-red scanning of NOAA-AVHRR data could be useful in detecting warm groundwater discharging into the Bay (possible person to contact is Fred Prater, CSIRO Atmospheric Research, Melbourne).

The Werribee Formation is the only known aquifer in the Port Phillip Region that has an anomalously high geothermal gradient of about 7^oC per 100 m (Leonard 1992). The gradient was measured in the Sorrento Graben on the Nepean Peninsula south of the Central Zone. Here the formation is more than 500 m deep and dissected by the Selwyn Fault. To the north of the Central Zone the Werribee Formation is shallower and groundwater flow moves laterally toward the Bay. Here the geothermal gradient is more normal at about 3.3^oC per 100 m.

6.3.2 Werribee - Altona Zone

This Zone stretches from Point Wilson to near the Maribyrnong River and is about 40 km wide (Figure 1). The predominant land use is associated with the WTC, market gardens and stock grazing. The area near Altona between Skeleton Creek and the Maribyrnong River has been extensively developed for residential and industrial purposes including oil refineries and chemical processing. This Zone can be further subdivided into a low pollution zone between Werribee River and Kororoit Creek and a high pollution zone between Kororoit Creek and the Maribyrnong River (Leonard, 1979).

The main aquifers discharging in the Zone are in the Werribee Delta sediments, the Newer Volcanics and the Brighton Group. Most of the discharge from the Newer Volcanics is as baseflow into creeks and streams which drain into Port Phillip Bay. Discharge from the Werribee Delta aquifer is mainly near-shore to the Bay. Groundwater pollution is not as serious as in the Altona Zone.

The Brighton Group aquifer in this Zone is locally confined and of low transmissivity and yield. Discharge may be into streams as baseflow or off-shore into Port Phillip Bay to the south of the extremity of the Newer Volcanics (Figure 2). Insufficient hydrogeological data do not allow for a detailed assessment of the outflow of the regional Brighton Group. The discharge rate is considered to be small compared to other aquifers. Leonard (1979) estimated a discharge rate of $5.6x10^5$ m^3y^{-1} for the Werribee - Altona Zone. Using a smaller hydraulic gradient in his more recent report Leonard (1992) derived a lower value of $7.5x10^4$ m^3y^{-1}.

A few chemical analyses indicate poor water quality (TDS 2500 - 8000 mg/l). Pollution of groundwater in the Brighton Group has not been assessed. Measurements of contamination west of Melbourne (and on the Bellarine Peninsula) have not been made. Contamination is likely when the Brighton Group is overlain and affected by the contaminated groundwater of the Newer Volcanics.

The groundwater regime in the Newer Volcanics aquifer system is complex. The system is anisotropic and inhomogenous, comprising a number of aquifers which are often separated by clay and silt aquitards. The uppermost, highly fractured and weathered aquifer is unconfined with a shallow water table whilst the deeper aquifers are semi-confined or confined. The Newer Volcanics aquifer system has been extensively investigated (Riha and Kenley, 1978; Stewart, 1988). Groundwater flow in the aquifer system is in a general southerly direction toward the Bay. Different discharge rate values have been reported for the Newer Volcanics basalts west of Melbourne (Leonard, 1979, 1992; Riha and Kenley, 1978; Stewart, 1988). Depending on the width or surface area of the selected discharge section, the transmissivities (or hydraulic conductivities) and hydraulic gradients, the discharge rates can vary by one order of magnitude. The regional groundwater flow for the segment between Melbourne and north of Geelong (60 km) ranges between $7x10^5$ and $4x10^6$ m^3y^{-1} (Leonard, 1992). These values are based on assumed regional transmissivity values and an assumed regional hydraulic gradient of 0.001. For the section between Werribee River and Kororoit Creek (20 km wide) Riha and Kenley (1978) estimated discharge rates of between $2.8x10^6$ and $1.6x10^7$ m^3y^{-1}, and for the Kororoit Creek - Maribyrnong River segment they calculated values between $2.3x10^6$ and $1.3x10^7$ m^3y^{-1}. The estimates of Riha and Kenley (1978) are based on sufficiently reliable hydrogeological data. Leonard's (1992) discharge values are clearly underestimated.

Riha and Kenley (1978) found for the region east of the Werribee River and the Altona Zone that less than 20% of the water within the system discharges directly into the Bay with the remaining groundwater discharging as baseflow into surface water channels, wetlands or by vertical leakage into the adjoining Brighton Group or Werribee Formation. Riha and Kenley (1978) derived this percentage value by comparing the discharge rates of the northern, unconfined shallow part with the southern semi-confined deeper part of the aquifer system. They concluded that since the discharge rate for the southern aquifer part is about 80% lower than the northern part, that the remaining water must have left the system as baseflow. The deflection of the iso-potential lines of the upper and lower aquifer of the Newer Volcanics aquifer system towards Kororoit Creek and the Maribyrnong River indicate groundwater input to the streams. The iso-potential lines seem also to show salt-water intrusion from the Bay. However, no direct baseflow calculations of individual streams by hydrograph techniques have been reported. It is not known if this baseflow is a source of contaminants to the Bay.

The variations in total dissolved solids (TDS) of groundwater in the Newer Volcanics ranges from less than 1000 to 14 000 mg l^{-1} (Riha and Kenley, 1978). There is no clear trend in the groundwater salinity distribution. It seems that the salinity is lower close to areas of recharge and increases towards the Bay. The salinity of groundwater discharging into the Bay is not known, but is expected to be moderate. Using an average salinity of 5000 mg l^{-1} (Leonard, 1992) and assuming a discharge rate of $5.8x10^6$ (20% of total through flow) for the areas east of the Werribee River to the Maribyrnong River, the salt load into the Bay would be approximately $2.9x10^4$ t y^{-1}.

In the report by Riha and Kenley (1978) the TDS distribution in the upper aquifer is shown for the period May 1972 and March-April 1975. Two centres of high TDS (greater than 10 000 mg $l^{-1)}$ were identified. The first was upstream of the Kororoit Creek, the second in the Altona-Brooklyn area near the Bay. The areas of high groundwater salinity increased over a period of three years and coincided with areas of high groundwater contamination by phenols and heavy metals (Leonard, 1979).

A report on Cherry Lake and Truganina Swamp indicates TDS concentrations in the upper basalt aquifer between 20 000 to 40 000 mg l^{-1} (Anderson, 1988a). Both drainage areas are located in a natural salt-marsh environment near-shore at Altona. The polluted Kororoit Creek discharges near Cherry Lake into the Bay. It is likely that groundwater does seep into the Bay from the lake (Anderson, 1988a). A petro-chemical industrial complex is located to the north.

Reports on the construction of the Western Trunk Sewer and North-western Sewer contain a few more recent salinity and groundwater pollution measurements from bores (Anderson, 1989). In the Western Trunk Sewer section groundwaters with TDS values of up to 20 000 mg l^{-1} were sampled.

No information is available on the input of nutrients and toxicants by groundwater from this Zone into the Bay. Nonetheless, the Altona Zone has the most polluted groundwater in the Port Phillip Region and is a potential source of contaminated groundwater input into the Bay.

Contamination of groundwater in the Newer Volcanics aquifer has been measured by DMID (e.g. Riha and Kenley, 1978; Shugg, 1981, 1992; Stephan *et al*., 1981), the EPA and MMBW. Routine measurements have generally occurred only since 1972. A regional assessment of sources of contamination in this area is constrained by the location of the monitoring bores. Pollution monitoring bores have generally been positioned to detect any release of chemicals from specific disposal sites. The groundwater pollution data reflects this bias and is not characteristic of the regional area. The possibility that at least part of any detected levels of pollutants may be attributed to cross-formational flow from more distant sources, including contaminated stream waters, further complicates interpretation.

Serious groundwater contamination has been observed in the uppermost unconfined aquifer of the Newer Volcanics system and, to a lesser extent, in the lower sections. The centres of high pollution levels are associated with disposal practices that have been discontinued (Leonard, 1979). The plume of contaminated groundwater emanating from pollution sources are elongated in the direction of groundwater flow and the concentration of pollution decreases down-gradient due to dispersion and attenuation. Available maps showing the distribution of phenols and lead in the upper aquifer are outdated (Leonard, 1979). In 1975 a contaminant plume between Kororoit Creek and Maribyrnong River of phenol concentrations greater than 0.2 mg l^{-1} discharged into the Bay (Leonard, 1979). In 1975 lead concentrations in groundwater ranged between 0.1 and 0.6 mg l^{-1} in the Altona Zone. Groundwater samples taken during the construction of the Western Trunk Sewer contained high concentrations of heavy metals, phenols and TOC. Lead values in the Brooklyn area ranged from 0.4 to 0.9 mg l^{-1}. A galvanizing plant in this area is the main source of toxicants. Previous reports mention that substantial residual lead concentrations are present in the groundwater and that these possibly present problems in meeting EPA limits (Anderson, 1988a).

The Cherry Lake and Truganina Swamp study obtained groundwater samples from test pits approximately 2 m deep (Anderson, 1988a). It is questionable whether these samples represent original groundwater from the basalt aquifer. The nitrate levels were low (0.02-0.08 mg l^{-1}) and the total phosphorus concentrations were elevated (0.1-0.8 mg l^{-1}). The total phenol concentrations were between 0.02 and 0.32 mg l^{-1}.

The pollution monitoring program presently conducted by the RWC assesses the level of groundwater contamination in the Altona Zone and should be used to identify and quantify sources of toxicant input by groundwater into the Bay.

Recommendation: The salinity distribution in the Altona Zone should be re-assessed. It is probable that the salinity of groundwater discharging into the Bay at Altona exceeds 10 000 mg l^{-1} TDS. The Rural Water Commission presently conducts a pollution monitoring program of the Altona-Newport-Brooklyn region. No reports are available yet.

As some boreholes are still accessible in the Altona Zone, it is recommended that monitoring of the groundwater re-commence. The monitoring should also include analyses for Cd, Cr, Ni, As and Hg.

The Werribee Delta is a coastal aquifer of about 117 km^2 located at the mouth of the Werribee River. The delta sediments mainly consist of lenticular sands and gravel bodies enbedded in clay and silt layers. The groundwater in the Werribee Delta aquifer is unconfined to semi-confined. The aquifer is underlain by the Newer Volcanics basalt aquifer system which thins out toward the Bay. The water table in the delta aquifer to the east of the Werribee River is less than 7 m deep, whereas at the WTC, west of the river, the water table is less than 2 m deep probably because of the development of a groundwater mound resulting from the seepage from the disposal lagoons. The regional groundwater flow direction is to the Bay. Hydraulic heads in the Werribee Delta aquifer system increase with depth (Anderson, 1988b; Stewart, 1988). The authors attributed the pressure increase to groundwater confinement beneath layers of impermeable sediments. It is questionable whether the clays and silts in the Werribee Delta sediments act as impermeable seals. The low permeable layers are laterally discontinuous (Anderson, 1988b; Coffey Partners International, 1992; Stewart, 1988). In a geologic time frame abnormally high pressures will dissipate to nominal formation pressures. The increasing pressures with depth clearly demonstrate that groundwater has an upward flow component. Hence, the delta area is a groundwater discharge zone. Cross-formational groundwater flow from the Newer Volcanics aquifer discharging to the Werribee Delta aquifer is likely. This also implies that downward migration of nutrients to deeper parts of the Werribee Delta aquifer system is inhibited by the upward flow of groundwater.

The outflow for a 8.5 km aquifer segment east of the Werribee River was estimated by Leonard (1992) to be 9.1×10^5 $m^3 y^{-1}$. Stewart (1988) reported greater discharge rate values of 2×10^6 $m^3 y^{-1}$ based on higher and better K-values and a steeper hydraulic gradient. The discharge rate for the part of the Delta west of the Werribee River (11 km wide) is about 5.1×10^5 $m^3 y^{-1}$ (Anderson, 1988b; Leonard, 1992). Coffey Partners International (1992) reported a total flow rate of 1.7×10^6 $m^3 y^{-1}$ which included groundwater flow into Little River and the Werribee River.

The salinity of the shallow groundwater ranges between 2000 and 10 000 mg l^{-1}. Water samples from standpipes installed in the shore zone indicated nutrient bearing groundwater with an average salinity content of about 14 000 mg l^{-1} which is lower than the salinity of the Bay water (between 18 000 and 27 000 mg l^{-1}).

The WTC is a major source of nutrient input into the Bay. In 1991 the annual nitrogen load *via* drains was about 4000 t y^{-1} and the phosphorus input about 1240 t y^{-1} (Anderson, 1988b).

In 1988 a groundwater study was conducted which produced information on the hydrogeology of the WTC area (Anderson, 1988b). Groundwater nutrient transfers to Port Phillip Bay were estimated on the basis of mean nutrient concentrations applied to calculated values of groundwater through-flow. The initial estimate for total nitrogen load to Port Phillip Bay of 9.7 t y^{-1} indicated that the input of nitrogen by groundwater is small in comparison to the direct discharge of effluent from the WTC drains. The Stage I study showed that for the coastal section underlain by silts of the Werribee Delta and the Newer Volcanics, more than 90% of the observed nutrient transfer by groundwater is occurring in the upper 5-6 m (Anderson, 1988b). Below this level the concentrations appear generally insignificant. However, for sites where the basalt is near the surface in the area of Western Lagoon and Little River, nutrients appear to migrate to deeper levels with high total nitrogen concentrations observed at depths of at least 15 m below the surface.

A Stage II groundwater study was undertaken to refine estimates of nutrient loads by groundwater to the Bay and to analyze the groundwater for heavy metal concentrations. Additional wells were installed to measure nutrient levels at greater depths and to estimate the nutrient transfer from the WTC to the Werribee River. The total nitrogen load entering Port Phillip Bay from groundwater (including baseflow load to Little River and Werribee River) is about 34 t y^{-1} (Coffey Partners International, 1992). The total phosphorus load to the Bay is estimated to be 8.1 t y^{-1} (Coffey Partners International, 1992). The 1992 measurements showed an apparent 20% increase in nitrogen concentrations in comparison to the 1988 samples. The reason for this increase is not known.

The heavy metal concentrations did not indicate significant groundwater contamination (Coffey Partners International, 1992).

6.3.3 Corio Bay Zone

The Corio Bay Zone has an area of about 165 km^2 (Zone 4, Figure 1). Hovell Creek discharges into the Zone. The water in Corio Bay is relatively shallow. Groundwater discharge is mainly from the Brighton Group (Moorabool Viaduct Sand) and from the Newer Volcanics aquifer (north shore).

The Brighton Group aquifer discharge rate cannot be estimated due to insufficient hydrogeological data. However, Leonard (1992) estimated a discharge rate of 7.5×10^4 $m^3 y^{-1}$ for the segment between Geelong and Melbourne.

The salinity is in the range of 2500 to about 8000 mg l^{-1} TDS.

Measurements of groundwater contamination in the Brighton Group have not been made. However pollution of groundwater in the Brighton Group as well as in the Newer Volcanics resulting from the pollution from petro-chemical plants in the North Geelong area is already evident (Leonard, 1979). Though data do not exist, pollution of the deeper aquifers (e.g. Batesford Limestone) is considered less likely, because they are overlain by the low-permeability Fyansford Formation.

Recommendation: A detailed assessment of the area is recommended to locate potential pollution centres, to evaluate their effect on groundwater quality, and to quantify the input of contaminated groundwater into the Bay.

6.3.4 Hobson's Bay Zone

Hobson Bay is that part of Port Phillip Bay located at Port Melbourne. The predominant influence on this zone is the discharge from the Yarra River, accounting for 52% of freshwater input into the Bay. The Port Melbourne area is comprised of the Yarra Delta sediments covering about 40 km^2. Of 5 sedimentary units only 2 units contain aquifers. The unconfined sand aquifer (Port Melbourne Sand) has a shallow water table. The salinity of the groundwater is generally between 2000 and 10 000 mg l^{-1} TDS. Salinities in excess of 40 000 mg l^{-1} TDS have been observed where the shallow groundwater is affected by discharge from the underlying unit (Shugg, 1987a).

No discharge rates are available. Data are limited to hydraulic parameters of the aquifers and information on the extent of groundwater pollution.

BP - site: A site of considerable groundwater and soil contamination is the British Petroleum (BP) storage and packaging terminal at Station Pier which was in operation for more than 40 years. Hydrocarbon spillage and leakage has occurred and it is estimated that 50 000 m^3 of Port Melbourne Sand is contaminated with light and heavy oils (Shugg, 1987a). A free hydrocarbon layer is floating on the water table 2 m below the surface. Natural discharge from the aquifer would be through the permeable sand sediments to the south and hence into Port Phillip Bay. The BP site has been proposed for re-development and a costly clean-up has been initiated.

Existing analyses of groundwater from the Port Melbourne Sands are biased because they represent conditions in the vicinity of the polluted location. The analyses include heavy metals and hydrocarbon pollutants (Shugg, 1987a). Groundwater discharge along the 200 m beach front about 40 m from the BP-site through a 1 m thick intertidal zone is estimated to be 36 500 m^3y^{-1} (Shugg, 1987a).

Gaswork site: Groundwater and soil contamination have been investigated at the gasworks site at Port Melbourne (Shugg, 1989a). Groundwater pollution has resulted from gas production effluents and coal tar derivatives and contaminated runoff water has entered the soil.

No surveyed groundwater levels are available for the site. It is assumed that the general groundwater flow direction is to Port Phillip Bay, which is about 500 m away (Shugg, 1989a). Without quantification of the hydraulic parameters the calculation and estimation of groundwater flow rates and discharge rates are speculative.

Water samples were taken in 1988. The analyses included major ions and a series of detailed organic analyses (e.g. naphthalene, benzols, pyrenes and polynuclear aromatic hydrocarbons (PAH)) in selected wells.

The groundwater in the Port Melbourne Sands at the site had a TDS between 500 and 3500 mg l^{-1} TDS. A sulphate concentration of 2000 mg l^{-1} was encountered in two bores.

The concentration gradients of the chemical compounds observed in the monitoring wells provide an indication of the flow direction and the movement of several organic species is related to their relative solubility in groundwater. PAH's were found at concentrations of 0.8 and 9 mg l^{-1}, with lower concentrations measured downgradient of the site.

At present the gasworks site has not been cleaned up. More bores have been installed near the site. Water levels indicate a groundwater depression under the site with flow direction radially downward. This is being interpreted - at least in a preliminary sense - as groundwater leaking into the underlying sewers (Shugg, pers. comm.).

Recommendation: More information and additional observation wells are required to interpret the migration pattern of soluble organic compounds to the Bay. A more regional water level monitoring network should be installed to determine groundwater flow trend and the extent of contaminant plumes.

6.3.5 Bellarine Zone

Land use on the Bellarine Peninsula is predominately rural with some development of holiday resorts. Most groundwater discharge is from the shallow unconfined to semi-confined Brighton Group. There is insufficient hydrogeological data to allow an assessment of the outflow of the regional Brighton Group aquifer. It is believed that the magnitude of discharge is small compared to other aquifers in the region. (Leonard, 1992). The few chemical analyses of groundwater from the Brighton Group indicate salinities between 2500 and 8000 mg l^{-1} TDS.

Measurements of groundwater contamination on the Bellarine Peninsula have not been made. Pollution of groundwater is, however, expected. Industrial waste has been discharged to above ground ponds and to a landfill in the Point Henry area. Septic tanks are used at the holiday resorts.

Recommendation: The hydrogeology and groundwater contamination on the Bellarine Peninsula should be investigated in more detail.

6.3.6 Nepean Zone

Land use on the Nepean Peninsula is dominated by holiday resorts. The unconfined Bridgewater Formation is the principal aquifer on the Peninsula and extends for more than 25 km from Point Nepean to the Selwyn Fault (Leonard, 1979). It covers an area of approximately 100 km^2 and is surrounded by the sea. The groundwater is in contact with the ocean water. A fresh water lens overlies the denser salt water (Leonard, 1992).

Discharge from the Bridgewater Formation occurs into both Port Phillip Bay and Bass Strait. The total outflow to the ocean and the Bay is estimated to be about 1.6×10^7 m^3y^{-1}. The discharge rate to Port Phillip Bay is about 8×10^6 m^3y^{-1} (Leonard, 1992).

Salinity ranges of between 300 and 1200 mg l^{-1} TDS have been measured and the salinity increases with depth due to the proximity of the fresh-salt water interface. Salinities greater than 2000 mg l^{-1} have been observed in coastal wetland discharge areas (Shugg, 1987b).

The main source of potential pollution on the Nepean Peninsula is effluent from domestic septic tanks located in unsewered residential and holiday resort areas along the Bay. Other sources of pollutants are agricultural seepages from the Boneo district and leachates from landfills.

High concentrations of nitrate (NO_3) have been measured in the groundwater of the Bridgewater Formation. The nitrate concentration pattern in groundwaters of the Nepean Peninsula has been investigated and documented by Shugg (1985, 1987b and 1989b). An extensive monitoring network (600 wells) and database are available. The nitrate data include measurements from 1968 to 1984.

Nitrate concentrations vary from below the analytical detection limit to 200 mg l^{-1}. The average is about 25 mg l^{-1}. The concentration of nitrate decreases with depth as nitrate is reduced to nitrogen. By regression analysis it is estimated that at a depth of about 30 to 40 m the groundwater is nitrate free (Shugg, 1985).

Nitrate "highs" occur on the Port Phillip Bay side and on the ocean side, but also north of Boneo. These zones coincide with areas of unsewered urban development. Areas of less than 10 mg l^{-1} nitrate are generally overlain by grassed farm land. It appears that nitrate levels are declining (Shugg, 1985), but this trend may only reflect new observation wells which have been constructed in areas without a history of domestic waste disposal. Older bores have not been sampled again since their construction.

Assuming a conservative nitrate concentration in groundwater of 15 mg l^{-1} and an assumed discharge rate of $8x10^6$ m^3y^{-1}, the nitrate load into Port Phillip Bay is about $1.2x10^2$ t y^{-1}.

Recommendation: Nitrate concentrations in groundwaters of coastal bores should be re-analyzed and the mass of nutrients moving into the Bay quantified.

6.3.7 South-eastern Zone

The South-eastern Zone is located south-east of Melbourne stretching from the Hobsons Bay Zone along the Bay to a position just north of Mornington (Figure 1). The dominant land uses are residential, business and rural. There are some industrial developments.

The principal aquifers in the area are the Fyansford Formation and the overlying Brighton Group (Leonard, 1992). These two hydrostratigraphic units have similar lithologies and hydraulic characteristics and are hydraulically connected. They are therefore referred to as one aquifer system: the Fyansford Formation - Brighton Group aquifer system

Underlying the Fyansford Formation - Brighton Group aquifer system is the Older Volcanic aquifer. In the Cranbourne-Mordialloc area the basalt thins towards the Bay. Based on a few transmissivity data and an assumed hydraulic gradient, Leonard (1992) estimates a discharge rate of $8.2x10^5$ m^3y^{-1} from a 10.5 km wide coastal segment between Mordialloc and Carrum. For the Mornington area further south, the discharge rate to the Bay is estimated to be approximately $2.8x10^5$ m^3y^{-1}. These coastal groundwater discharge segments from the Older Volcanics aquifer system coincide with areas of wetlands and swamps. Ascending groundwater from the Older Volcanics aquifer probably discharges into the Fyansford Formation - Brighton Group aquifer system but has this not been investigated.

Data on the chemical composition of groundwater in the Older Volcanics in the South-eastern Zone is limited and restricted to regions of recharge. No chemical data are available on groundwater near the coast. Pollution of groundwater in the Older Volcanics has not been detected.

Groundwater discharge from the Fyansford Formation - Brighton Group aquifer system occurs into Port Phillip Bay both on-shore and off-shore. Coastal swamps and wetlands are manifestations of groundwater discharge from this aquifer system.

Salinity in the Fyansford Formation - Brighton Group aquifer is extremely variable ranging from 110 to 6800 mg l^{-1} TDS. The TDS is higher in the Fyansford Formation. Towards Frankston the salinity of groundwater improves to less than 1000 mg l^{-1} TDS (Leonard, 1992).

The South-eastern Zone is sub-divided into three segments based on geological, groundwater quality considerations and water table configurations (Leonard, 1992). The compartmentalization of the Fyansford Formation - Brighton Group aquifer system in the Zone is basically controlled by the fault system in the area. Leonard (1992) describes these segments as different hydrogeological regimes. It is questionable that these are different regimes. The general groundwater flow direction in the segments is toward the Bay. It is one groundwater flow system locally modified by different hydrogeological environments.

A Northern Segment extends from St. Kilda to Mentone. It is underlain by the Silurian Basement. The water table is less than 6 m below surface. Groundwater flow is in a westerly direction and discharge is near-shore into the Bay. Coastal discharge along 18 km of shore-line is estimated at $2x10^6m^3y^{-1}$ (Leonard, 1992). The salinity is moderate.

In the Central Segment the water table is near the surface. The Carrum swamp and Dandenong Swamp are manifestations of upward leakage and diffuse discharge of groundwater from the aquifer system. The high salinity is attributed to groundwater evaporation. Surface drainage of the discharge area is inhibited by sand dune ridges extending parallel to the coast. It is believed that the dunes generate local flow systems which converge with the regional flow system and thus constitute a hydraulic barrier to shallow, lateral groundwater flow to Port Phillip Bay (Walker, 1990). Salinity of groundwater in the sand dunes is low and the water table is elevated. The depth of the local flow system is not known and hydrogeologic data are lacking to substantiate this hypothetical interpretation on groundwater flow barriers and quasi-stagnant zones. Further it is not known if these groundwater flow "cells" restrict deeper lateral flow from the Fyansford Formation - Brighton Group aquifer system to the Bay. The existing data in the area is insufficient to determine the nature and interaction of these flow systems.

Nonetheless, the discharge rate from this zone has been estimated to be $6x10^5$ m^3y^{-1}. Discharge occurs offshore into Port Phillip Bay along a 20 km wide segment (Leonard, 1992).

A Southern Segment extends from Frankston to the south of Mornington. Here groundwater salinities are more than 3000 mg l^{-1} TDS. Along a coastal discharge segment of 15.5 km groundwater discharge has been estimated to be approximately $1x10^6$ m^3y^{-1} (Leonard, 1992).

The total discharge rate from the Fyansford Formation - Brighton Group aquifer system in the South-eastern Zone is approximately $3.6x10^6$ m^3y^{-1}.

The density of septic tanks in coastal areas (Mornington) and the use of old sand pits for waste disposal render the Fyansford Formation - Brighton Group aquifers vulnerable to contamination.

The pollution monitoring program in this Zone has mainly been concerned with waste disposal sites (Leonard, 1979). The Brighton Group aquifer is particularly susceptible to groundwater pollution. The water table is often shallow and at the base of the disposal sites. The Fyansford Formation is not quarried but contaminated groundwater from the Brighton Group can infiltrate downward. The vertical hydraulic gradient indicates a downward flow direction (Leonard, 1979).

Groundwater near disposal sites is polluted by leachates containing reduced compounds, phenols, surfactants, lead and manganese. The organic content has not been comprehensively analyzed.

The monitoring data are outdated and sampling is biased.

No regional study has been conducted on the extent of contaminated groundwater and the input of nutrients and toxicants from this Zone into the Bay can not be determined.

Recommendation: Hydrogeological cross sections of the South-eastern Zone to the Bay should be constructed to evaluate the aquifers' hydraulic communication and to study the input of groundwater and nutrients into the Bay.

7.0 Conclusions

The review of groundwater discharge, nutrient and toxicant inputs by groundwater into Port Phillip Bay is based on numerous published and unpublished reports which describe the hydrogeology and groundwater contamination near waste disposal sites. The only report that has been written on the input of groundwater and toxicants into the Bay is the WTC study (Anderson, 1988b). Most of the disposal site reports are from the 1980's and outdated. The most current regional report by Leonard (1992) is a compilation of older reports. Coffey Partners International (1992) published a recent report on groundwater and nutrient discharge by the WTC. The Rural Water Commission is presently conducting a groundwater pollution monitoring program in the Altona-Brooklyn-Newport area.

The methodology applied to calculate discharge rates along coastal segments is only indicative of possible discharge rates. Given the sparsity and bias of hydraulic data and aquifer parameters this methodology is adequate for a regional analysis but is not quantitative. Estimations of discharge rates could be improved by flow net construction and by modelling.

The hydraulic connectivity between principal aquifers is not well understood. There are indications that sub- and super-hydrostatic pressure gradients between regional aquifers exist and that pollutants move between aquifers in groundwater flow (e.g. Altona). The construction of hydrogeological cross-sections parallel to the regional groundwater flow direction to the Bay are regarded as the appropriate method to review aquifer interconnectivity, groundwater discharge and pollutant migration patterns. In particular, hydrogeological cross sections should be constructed for the pollution zones west and south-east of Melbourne and for Corio Bay.

Except for the recent WTC study, no direct hydrogeological and chemical measurements have been taken to analyze groundwater and contaminant inputs into Port Phillip Bay.

The total groundwater discharge rate into the Bay is greater than 5.5×10^7 $m^3 y^{-1}$ (Table 1). Considering that the total volume of water in Port Phillip Bay is about 2.5×10^{10} m^3, it seems that the groundwater contribution to the Bay is relatively small. However, the total discharge rate does not include groundwater inputs from the Central Zone nor does it include Corio Bay and the Bellarine Peninsula.

The baseflow component of stream and rivers has not been evaluated. Nonetheless, this component is considered substantial for the area west of Melbourne (about 80%). The contribution of baseflow as a source of contamination is unknown.

Heat input by forced-convection into the Bay is not known. High geothermal gradients in the deeper aquifer under the Bay have been measured and heat input by conductive faults into the Central Zone, off the coast of the Bellarine and Nepean Peninsulas' is most likely.

Aquifer contamination in the Port Phillip region is widespread and serious. Discharge Zones of nutrient and toxicant input by groundwater flow into the Bay have been identified for the Werribee and Altona areas, the Port Melbourne and South-east areas, Corio Bay, the Bellarine and Nepean Peninsulas (Table 1; Figure 2).

Input of pollutants by groundwater into Corio Bay and by aquifers of the Bellarine Peninsula is not known and has to be investigated in more detail. It is possible that consultant companies have conducted confidential, local studies for private firms.

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