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An Approach to the Management of Groundwater Resources to Protect and Enhance Fish Habitat

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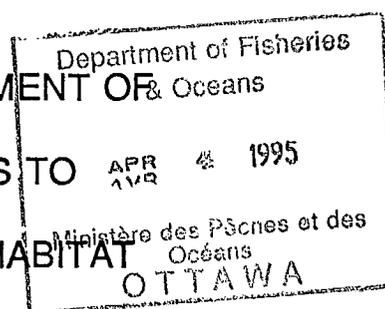
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AN APPROACH TO THE MANAGEMENT OF
GROUNDWATER RESOURCES TO
PROTECT AND ENHANCE FISH HABITAT



by

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TABLE OF CONTENTS

	<u>page</u>
ABSTRACT/RÉSUMÉ	vii
ACKNOWLEDGEMENTS	viii
PREFACE	ix
1.0 INTRODUCTION	1
2.0 THE RELATIONSHIP BETWEEN GROUNDWATER AND FISH HABITAT	2
2.1 The Link Between Groundwater and Fish Habitat	2
2.1.1 Baseflow Characteristics	2
2.2 Baseflow Relationships	3
2.3 Temperature Relationships	4
2.4 Relationships of Groundwater to Fish Spawning and Nursery Habitat	5
3.0 OVERVIEW OF GROUNDWATER FLOW	6
4.0 OVERVIEW OF POTENTIAL LAND USE IMPACTS ON GROUNDWATER RESOURCES PERTAINING TO FISHERIES	11
4.1 Introduction	11
4.2 Aggregate Extraction	11
4.3 Urban Land Use	15
4.4 Rural Land Use	18
4.5 Groundwater Withdrawal	20
4.6 Summary	22
5.0 GROUNDWATER PROTECTION STRATEGIES	23
5.1 Introduction	23
5.2 Decision Framework and Flow Chart	24
5.2.1 Assessment of Existing/Potential Fisheries Habitat	25
5.2.2 Initial Screening: Assessment of Fisheries Habitat Attributes ..	25
5.2.3 Level of Assessment: Potential Fisheries Related Groundwater Impacts from Changing Land Uses	26
5.2.4 Level of Assessment: Potential Function of the Hydrogeological Setting	28
5.3 Summary	30

TABLE OF CONTENTS

	<u>page</u>
6.0 ASSESSMENT OF POTENTIAL IMPACTS OF LAND USE CHANGES ON GROUNDWATER RESOURCES AS RELATED TO FISHERIES HABITAT	31
6.1 General Information Requirements	31
6.2 Summary	35
7.0 SUMMARY	36
8.0 REFERENCES	38
TABLES	40
FIGURES	42
APPENDIX	66

LIST OF TABLES

<u>Table</u>	<u>page</u>
1. Potential Fisheries Related Groundwater Impacts From Land Use Activities	40
2. Potential Function of the Hydrogeologic Setting	41

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
1. Groundwater Flow in a Simple Geological Setting	42
2. Influence of Clay Layer on Groundwater Flow	43
3. Groundwater Flow in a Complex Geologic Setting	44
4. Generalized Groundwater Flow	45
5. Aggregate Extraction (Sand and Gravel), Example of Existing Conditions	46
6. Aggregate Extraction (Sand and Gravel), Example of Potential Impact	47
7. Aggregate Extraction (Sand and Gravel), Example of Mitigation of Potential Impacts.....	48
8. Aggregate Extraction (Bedrock), Example of Existing Conditions, Plan View	49
9. Aggregate Extraction (Bedrock), Example of Existing Conditions, Cross-Section	50
10. Aggregate Extraction (Bedrock), Example of Potential Impact, Cross-Section	51
11. Aggregate Extraction (Bedrock), Example of Potential Impact, Plan View .	52
12. Aggregate Extraction (Bedrock), Example of Mitigation Impacts, Plan View	53
13. Aggregate Extraction (Bedrock), Example of Mitigation Impacts, Cross-Section	54
14. Aggregate Extraction, Example of a Regional System	55
15. Urban Land Use Changes, Example of Existing Conditions	56
16. Urban Land Use Changes, Example of Development Impacts	57
17. Urban Land Use Changes, Example of Mitigation of Development Impacts	58
18. Rural Land Use Changes, Example of Present Conditions	59

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
19. Rural Land Use Changes, Example of Potential Impacts	60
20. Rural Land Use Changes, Example of Potential Impact Controls	61
21. Groundwater Withdrawal, Example of Present Conditions	62
22. Groundwater Withdrawal, Example of Potential Impacts	63
23. General Framework	64
24. Decision Flow Chart	65

LIST OF APPENDICES

<u>Appendix</u>	<u>page</u>
A. Summary of Field Methods	66
B. Glossary	68

ABSTRACT

Blackport, R., R. MacGregor, and J. Imhof. 1995. An approach to the management of groundwater resources to protect and enhance fish habitat. *Can. Manuscr. Rep. Fish. Aquat. Sci.* 2284: 70 p.

Groundwater is important to fish habitat for a number of reasons, such as, creating baseflows, generating opportunities for reproduction, and moderating stream temperatures. When developments such as groundwater extraction, aggregate extraction, urban and rural developments are proposed, due consideration must be given to protect and maintain groundwater resources in order to protect and maintain fish habitat and fisheries.

This report, through examples of geological/hydrological scenarios, discusses potential development impacts on groundwater resources. A general framework and logic tree are presented as well as groundwater resources assessment techniques, as related to fish habitat.

The intention of this report is to stimulate a 'thought process' for the protection of fish habitat through groundwater management.

RÉSUMÉ

Blackport, R., R. MacGregor, and J. Imhof. 1995. An approach to the management of groundwater resources to protect and enhance fish habitat. *Can. Manuscr. Rep. Fish. Aquat. Sci.* 2284: 70 p.

Les eaux souterraines sont importantes pour l'habitat du poisson pour un certain nombre de raisons, entre autres l'établissement de débits de base, la création de milieux de reproduction et la modulation de la température des cours d'eau. Les projets de développement, comme le pompage des eaux souterraines, l'excavation d'agrégat, le développement rural et urbain, devraient tenir compte de la protection et du maintien des ressources en eaux souterraines de sorte à protéger et à maintenir les habitats du poisson et les pêcheries.

À partir de scénarios basés sur la géologie et l'hydrologie, on examine dans le présent rapport les impacts potentiels du développement sur les ressources en eaux souterraines. On présente un cadre général et un arbre logique, ainsi que des techniques d'évaluation des ressources en eaux souterraines, applicables à l'habitat du poisson.

L'objectif du présent rapport est de stimuler la réflexion au titre de la protection de l'habitat du poisson par l'entremise de la gestion des eaux souterraines.

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PREFACE

There has been a continuing need to discuss the protection of groundwater resources, as it relates to fish habitat and fisheries, from changing land use impacts. This document has been prepared to provide a sound rationale for the management and protection of groundwater as it relates to fish habitat. The paper focuses on understanding the cause and effect relationship between groundwater and fish habitat and fisheries, then it develops an approach to general assessments and studies appropriate for a variety of land use scenarios.

Obviously not all land use changes and geologic settings can be presented, however, the discussions included are meant to initiate a 'thought process' for the users and to aid in dialogue between regulatory agencies (e.g. OMNR and Conservation Authorities) and proponents of proposed land use changes. In addition, this paper provides a framework for review agencies to work within to ensure a more consistent approach to the review of projects that may impact groundwater resources.

It must be stressed that there are many ways of carrying out groundwater assessments, as it relates to fish habitat and fisheries. Many of these assessment methods are presented in this document, though this is not an exhaustive listing and other methods may be available.

We acknowledge that a better scale for dealing with groundwater issues as they relate to fish habitat and fisheries, would be at the watershed or subwatershed level, however in the absence of these types of studies we present this approach for assessing the impacts of changing land uses.

1.0 INTRODUCTION

Groundwater resources in the context of fisheries habitat differ from what might typically be considered groundwater resources in the context of water supply. While significant supplies of water may be utilized for development purposes, much less water may be necessary to maintain fisheries habitat, however, this water may provide an extremely critical function related to fisheries habitat, based on quality, temperature, how it enters a streambed, etc.

The emphasis in this document is on groundwater as it relates to fish habitat; we consider groundwater discharge to be an important (if not critical) component of fish habitat from both a quantity and quality perspective. Hence, reductions or disruptions of groundwater discharge is considered to be a harmful alteration of fish habitat, contrary to Section 35 (1) of the Federal Fisheries Act. Therefore, both provincial (OMOEE and OMNR) and federal review (DFO) agencies will be involved when potential groundwater issues affecting fish habitat emerge.

It should be noted that this focus is related specifically to fisheries issues, however, this document should be utilized in conjunction with other regulations under various articles and statutes of the Environmental Protection Act (EPA) and the Ontario Water Resources Act, in particular those related to discharge of contaminants to groundwater and groundwater withdrawal. Groundwater quality, although discussed in some sections, is not a significant component of this document, as the emphasis is on maintaining the quantity of groundwater. Enforcement of groundwater contamination legislation, is usually more rigorous and has generally a higher public profile than the issues discussed in this document.

The document is divided into the following six basic sections: 1) a basic understanding of the relationship between groundwater and fish habitat; 2) principles of groundwater recharge and discharge; 3) activities potentially impacting groundwater resources; 4) groundwater protection strategies; 5) a discussion of general methodologies related to coordinating studies under different settings or potential types of impacts; and 6) an overview of groundwater protection strategies. It is felt that prior to providing an overview of groundwater protection strategies, a basic understanding of fisheries habitat and groundwater is required to provide the framework for developing groundwater protection strategies. This provides a 'common' starting point to understanding the interrelationship between fisheries habitat and groundwater.

2.0 THE RELATIONSHIP BETWEEN GROUNDWATER AND FISH HABITAT MAINTENANCE

2.1 The Link Between Groundwater and Fish Habitat

A strong positive relationship between the discharge of groundwater to streams and stream fish production has been a common observation by field biologists for many years. Nevertheless, only recently have the relationships been explored scientifically. Some recent work in this area includes "Trout biomass and habitat relationships in southern Ontario streams" (Bowby and Roff, 1986), "Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrate" (Sowden and Power, 1985), "Relationship of young-of-the-year trout to mature trout and groundwater" (Latta, 1965), "Redd-site selection by brook trout and brown trout in southwestern Ontario streams" (Witzel and MacCrimmon, 1983), "Some effects of groundwater on brown trout redds" (Hansen, 1975), and "Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*)" (Cunjak and Power, 1986). In addition to fish directly, groundwater has also been identified as important, in general, to stream ecosystems: "Characteristics and frequency of coolwater areas in a western Washington stream" (Billby, 1984); "Groundwater and stream ecology" (Hynes, 1983); and "The role of groundwater in the impact of climate warming on stream salmonines" (Meisner et. al., 1988). While there is still much to learn, several important relationships between fish and groundwater have been demonstrated, including:

- A) Groundwater discharge creates baseflow in streams, and hence controls the quantity of living space, cover and food for fish.
- B) Site-specific groundwater discharge patterns generate opportunities for reproduction and provide thermal refugia during temperature extremes.
- C) Groundwater moderates stream temperatures during critical times of the year (midsummer and midwinter), and maintains temperatures to a level suitable for thermally sensitive fish species. Groundwater also maintains other water quality requirements such as dissolved oxygen.

2.1.1 Baseflow Characteristics

Biologists are aware that many factors control the 'productivity' of fish and related communities in streams. The quantity of water, its quality, its source (ie. shallow groundwater vs regional groundwater), and its delivery to the stream, have a major control on fish habitat and aquatic communities.

Research in recent years has demonstrated that some of the most productive streams are spring-fed streams that exhibit little fluctuation in flow pattern on an annual basis.

Groundwater, the source of water that generates these conditions, has been shown in a number of studies to be highly correlated to fish biomass and productivity (e.g. Bowlby and Roff, 1986).

Changes in frequency, magnitude and duration of stream flows due to land use modifications, result in the depletion of fish communities, stream habitat structure and usually concurrent degradation of water quality (e.g. Klein, 1979). This also results in modifications of the hydrologic characteristics of the stream represented by flashier, more frequent high flow events of shorter duration, modifications of sediment budget and channel morphology and modifications in the low flow patterns of the stream (i.e. lower baseflows for longer periods).

Stress can be placed upon fish through natural extreme fluctuations in stream flows both from an event standpoint (e.g. 1:25yr flood; 1:25yr drought) and from a regime standpoint (e.g. changes in the 'normal' daily, seasonal or annual flow characteristics of frequency, magnitude and duration). Headwater streams of 1st and 2nd order are more sensitive to daily and seasonal fluctuations in stream flow because of the characteristics of their morphology (i.e. relatively shallow pools and refuge areas). For example, an increase in minimum low flow events in headwater streams (over and above natural stochastic events) can lead to the loss of spawning success, loss of juvenile fish and depletion of adult fish. Medium order streams (3-4 order) usually have deeper water refugia and because flow is contributed by a larger network, they may have more variability in flow, but low flow characteristics are not as variable in relation to channel characteristics as in headwater systems. Large order streams (i.e. 5-8 order) have dampened hydrographs that generate longer durational characteristics to low and high flows. Major droughts also affect these larger order streams but the return periods are less frequent.

2.2 Baseflow Relationships

Stream flow is a combination of overland flow, interflow (flow below the ground surface but above the water table) and groundwater discharge; however, it is the constant discharge of groundwater that maintains baseflow in streams during periods of little or no precipitation. Baseflow is an important determinant of such critical fish habitat features as living space and cover availability. In addition, living space for benthic macroinvertebrates (important food items for many fish species) is controlled largely by baseflow. In particular, the living space in riffle areas (important production areas for benthos) is strongly linked to baseflow. Clearly, baseflow ultimately controls the maximum potential productivity of a stream or river system by determining the amount of living space for aquatic biota.

Baseflow is not a single value. 'Baseflow' volumes will vary in a stream throughout the year and between years depending upon the time of year, the previous precipitation characteristics of the past season or year, extent of soil saturation and the height and

slope of the water table.

Baseflow has been examined using the same parameters as high flow (i.e. frequency, magnitude and duration). The usual means of analyzing and developing this information (as with high flows) has been through event simulation (e.g. 1:5yr storm; 1:25yr storm; regulatory storm). Biologists often use the term 'baseflow' as an expression of the low flow characteristics of a stream. This term denotes a type of condition rather than a specific 'value'. In order to be successful, baseflow analysis must include:

- the low flow regime (frequency, magnitude and duration in relationship to mean baseflow, seasonal variance, responsiveness, etc.) over the course of a season, over the year and between years (i.e. continuous simulation);
- the concept of minimum low flow events (e.g. extreme low flows that do not occur seasonally or yearly) as well as;
- consideration of both regime characteristics of the stream and event characteristics, both placed in context with the size and complexity of the stream and its channel.

Baseflow maintenance refers to the management of low flow conditions and characteristics in a stream. Specifically, fish are adapted to the conditions of the stream system they reside within and have developed compensatory life history behaviour to allow them to survive and function in a stream that has a certain flow regime. Sudden changes in the baseflow characteristics in a stream, depending upon the size of the stream and complexity of the channel (i.e. number and quality of pools, etc.), can severely stress fish by shrinking available wetted habitat and exposing fish to predation or lack of sufficient water depth.

2.3 Temperature Relationships

Groundwater travels much more slowly than surface water and it cools as it moves slowly through the ground. As a result the temperature tends to be at the mean annual soil temperature (in southern Ontario normal groundwater temperatures are 7-10°C). As groundwater discharges to streams at temperatures considerably cooler than late summer air temperatures (and at temperatures warmer than midwinter air temperatures), groundwater imparts an important moderating influence on stream temperatures. In summer, wide diurnal variations in stream temperatures can be observed in small streams with little groundwater influence (fluctuations of 6°C or more have been documented over the course of a summer day in some streams, Hynes, 1970). This is a function of both daytime temperatures warming the surface water and an increase in discharge at night due to decreased evapotranspiration. Inflow of relatively cool groundwater helps to moderate these fluctuations, which can be stressful to fish, and maintains stream

temperatures within thermal tolerance limits of sensitive fish species (e.g. salmon and trout). In addition, if daytime temperatures climb to levels that are stressful, areas of groundwater discharge provide thermal refugia (large numbers of trout have been observed congregating at points of groundwater discharge when stream temperatures become excessive) and also enable sensitive species to recover from thermal stress by quickly reducing stream temperatures when the sun sets. In winter, groundwater discharges at temperatures warmer than ambient stream temperatures thereby moderating temperatures upwards; warmer winter temperatures lead to reduced mortality of all age classes of fish, particularly embryos and juveniles (Cunjak and Powers, 1986; Latta, 1965).

2.4 Relationships of Groundwater to Fish Spawning and Nursery Habitat

Groundwater discharge may have a major influence on spawning and nursery habitat potential for many fish species. For instance, Cunjak and Power (1986) demonstrated that brook trout (*Salvelinus fontinalis*) require groundwater discharge areas for spawning, nursery and juvenile habitat. Latta (1965) also found higher juvenile survivorship in areas having active groundwater discharges. Localized groundwater discharge through stream beds ('upwelling') provides a stable flow of clean water through salmonid redds, and is critical in many instances for egg and embryo survival. A positive correlation between salmonid embryo survival and groundwater discharge has been clearly demonstrated in many scientific studies (e.g. Benson, 1953; Wickett, 1954; Sowden and Power, 1985). As groundwater discharge temperatures are relatively warm in winter relative to 'surface water', groundwater flow through redds promotes rapid egg development and prevents mortality due to freezing and anchor ice development.

Once they emerge from the gravel, salmonid fry inhabit the slower, shallow stream margins where temperatures in these important microhabitats may be expected to be subject to extremes (depending on fluctuations in air temperatures). As groundwater upwelling pressures are greatest at stream margins relative to the centre of a stream (Sowden and Power, 1985), temperatures along stream margins will be moderated by groundwater discharge, thereby maintaining thermal conditions suitable for salmonid fry.

Wetlands provide extremely important spawning and nursery habitat for many fish species, and they are also important habitat for waterfowl and wildlife. Some wetlands may serve as important groundwater recharge areas (e.g. wetlands on higher ground), whereas others in low-lying areas are discharge areas and receptors for significant amounts of groundwater. Because of the dependence of the wetland plant community on the water table level and groundwater flow, changing the discharge patterns of groundwater or lowering the water table in these areas may substantially influence the wetland and all the organisms depending on it.

3.0 OVERVIEW OF GROUNDWATER FLOW

The previous discussion illustrated the relationship between groundwater and fisheries habitat, however as fisheries habitat becomes increasingly stressed as a result of land use alterations, a sound understanding of groundwater flow is necessary and hydrogeological investigations are required to better establish the physical linkages between groundwater flow and fisheries habitat. Because of the direct linkage of fisheries habitat to groundwater, it is safe to assume that the more important or sensitive a fisheries habitat is in a particular area, the more important the hydrogeologic setting and understanding of groundwater flow. This section develops a basic understanding of relevant issues, in particular the main hydrogeologic processes of recharge and discharge and the concept of scale of groundwater movement from local to regional groundwater flow systems.

Obviously, there are textbooks written on the subject of groundwater/hydrogeology and this cannot be summarized into a few short pages in this document. Key elements and processes however, are discussed here as they relate generally to stream flow and specifically to potential impacts from land use changes. Understanding the general processes affecting the movement of groundwater will allow the development of a framework to assess the potential impacts from various land uses, as shown with specific examples in later sections.

To understand the basic processes one has to understand the basic hydrologic cycle as it pertains to the issues of concern in this document, with the focus on groundwater recharge and groundwater discharge. It is assumed that readers will have a reasonable understanding of the hydrologic cycle, however, if a more extensive understanding is required most textbooks on hydrology or hydrogeology will have a detailed section.

The component of the cycle that is important to fisheries habitat is the land based portion of the cycle. The size or scale of the land area or watershed area to be examined depends on the geology and topography of the area. Figure 1 presents a schematic representation of the relevant aspects of the hydrologic cycle and the concept of scale related to geologic and topographic controls.

In general the land based part of the hydrologic cycle begins with rain or snow falling on the ground. This water either runs off across the ground surface directly to a surface water course, infiltrates or percolates into the ground or goes back to the atmosphere by evapotranspiration. It is the water entering the ground that is of importance from a fisheries habitat perspective. It is critical to understand how this water moves through the ground to its ultimate point of discharge back to the atmosphere.

For most of the hydrologic conditions dealt with in this paper the water table can be defined as: "the depth below the surface of the soil at which the soil is saturated", more

specifically though, it is defined as "the surface on which the fluid pressure in the pores of a medium is exactly atmospheric (Freeze and Cherry, 1979).

Interflow is defined as: "precipitation which infiltrates the surface soil and moves laterally through the upper soil horizons toward the streams as ephemeral, shallow, perched groundwater above the main groundwater level" (Chow, 1964).

When this water reaches the water table it is said to recharge the water table. A discharge area is simply defined as an area where groundwater moves away from the water table.

Groundwater generally moves through the ground slowly (centimetres to ten's of metres per year) usually taking months to decades to resurface or discharge at streams, springs or wetlands. The location of this discharge depends on both regional topography and geology, and stream geomorphology. Geomorphology is simply defined as the study of land forms and therefore stream geomorphology is the study of fluvial or river processes that affect land forms.

In its most simple form a groundwater discharge area is an area where groundwater movement is directed away from the water table. If a stream or wetland is part of the water table then groundwater may discharge to the water table. In a wetland area, groundwater may discharge to the wetland, though no surface water flow may be noted, because the water could be lost to evapotranspiration.

To better understand the concept of recharge and discharge and the groundwater movement that links them together, an understanding of the geologic system is critical as much of the flow of water is dependent on the three dimensional nature of geologic deposits. The other key factor is topographic relief, as this affects the scale of the linkages of recharge and discharge. To better visualize the factors that govern the movement of water a series of cross-sections are presented and discussed below. It must be remembered that these are two dimensional cross-sections and that the third dimension is always present and especially important in the discharge area because of the nature of fluvial processes. Geomorphologic conditions will also influence the areas of discharge or upwelling in streambeds depending on the coarseness and stratified nature of the material. For example, sedimentation of upwelling areas, may inhibit discharge.

In Figure 1 groundwater flows under idealized geologic conditions (a uniform sand) with variable topographic relief. It is noted that there are two discharge areas, one at the streambed and adjacent flat lying area and one at the base of a hill (i.e. a break in relief or gradient). On a local scale the direct discharge (upwelling) to the streambed is important from a spawning perspective. From an overall fisheries habitat perspective, direct discharge to the stream, discharge to the adjacent flat lying areas and interflow all contribute to maintaining baseflow volume. This water helps to moderate the stream

temperature both in the summer and winter. It is important to recognize the distinction between direct discharge and volume of baseflow from the perspective of impacts as discussed in the previous section.

On a local scale the actual discharge in Figure 1 is primarily controlled by local geologic and topographic conditions, in particular in and near stream geomorphology. However, in order to maintain baseflow it is critical to maintain groundwater recharge to the area 'contributing' water to a particular discharge area. Although this is a simple concept, it is generally far easier to determine areas of groundwater discharge than it is to determine the recharging source area of this water. Figures 1 through 3 provide examples of the geologic and topographic controls that affect linkages between recharge and discharge areas.

Figure 1 shows three general types of recharge in different areas of the cross-section. Area 1 shows a very localized recharge/discharge area. In other words, water that infiltrates locally to the water table moves a short distance through the ground and discharges locally. Because groundwater generally moves at a slow rate, on the order of centimetres per year in fine-grained soils to ten's of metres per year in coarse grained soils, local recharge/discharge travel times would likely be on the order of several months to several years. Local conditions will determine the length of travel time in the soil required to sufficiently cool groundwater for moderating stream temperatures.

Localized discharge or upwelling in a streambed is primarily maintained by local recharge. Since minor variations in recharge areas may impact the discharge zone, land use impacts must be thoroughly examined to ensure that the recharge areas are not adversely effected. Such an approach implicitly ensures that the natural discharge zone will thereby remain at the natural source. Although modifications to the infiltration by a particular land use change may not have a measurable effect on the overall baseflow, consideration must be given to the altering of spawning habitat. Obviously, a sound database, with respect to fisheries assessments in a local scale will aid in understanding the importance of the local hydrogeologic conditions.

The second area of recharge, Area 2 in Figure 1, shows local recharge farther away from the stream bed (i.e. further up the valley, topographically) with the water recharging both local discharge areas, such as springs or wetlands, based on topographic relief, and discharge areas farther from the source of recharge. This recharging water generally aids in maintaining baseflow, while it is likely that significantly smaller volumes of water directly discharges to the main stream. Generally, it is not so much the specific recharge location that influences this discharge but rather the elevation of the water table (i.e. hydraulic head) that creates the pressure to drive the water through the particular geologic setting. This means that if these recharge areas were to be altered there would be more flexibility to recharge water within the general source area without causing significant impacts on baseflow and direct discharge.

The third area of recharge (Area 3 in Figure 1) is a regional recharge area. Water in this area generally infiltrates to the regional groundwater flow system and moves through the regional aquifer system ultimately discharging into a much larger basin such as a major river basin (e.g. Grand River), or lake basin (e.g. Lake Ontario), or some of this water may discharge locally, depending on the physical setting and topographic relief, such as locally deeper cut valleys. Travel times of groundwater from these recharge areas to discharge areas could be from ten's to hundreds of years. Shifting recharge zones within a large source area of recharge would likely have little impact on discharge. The key is to maintain the water table level in the recharge or upland areas. Altering the quantity of recharge to the groundwater zone in these areas may not result in noticeable impacts for many years, as there would have to be a sufficient reduction in water levels in these areas to reduce the pressure that 'drives' the water through the system.

The above discussion was based on the simplified geology in Figure 1, which shows only a permeable homogeneous sand layer. Obviously as the geologic complexity increases, the complexity of groundwater flow and recharge/discharge aspects also increase. For example, Figure 2 shows the addition of a clay layer east of the stream, and the influence it has on groundwater flow. The majority of water which recharged this area will not recharge the regional aquifer or directly discharge to the stream. Much of the water would seep out of the side of the hill where the clay is a ground surface and flow overland to the main stream (likely a drainage channel would be formed here). Compared to Figure 1, there is less flow to the regional aquifer, less direct discharge (upwelling) to the stream, and increased baseflow volume from the local discharge area to the creek.

Because of the complexity of the way geologic materials were laid down during various periods of glaciation throughout most of southern and central Ontario, the geology is generally more complex, such as the scenario shown in Figure 3. This figure is presented to illustrate several aspects of groundwater flow. A low permeability zone at ground surface on the western portion of the cross-section illustrates an area where recharge or infiltration is limited to both the shallow groundwater zone and the deep groundwater zone. The extensive low permeability zone on the eastern portion of the cross-section indicates little recharge to any portion of the flow system.

The distribution of sand and low permeability material (i.e. silt or clay till) results in a complex interconnected aquifer system. Water taking from various parts of the aquifer system will have different impacts on the groundwater flow system and groundwater discharge.

The above discussion is meant to illustrate that whether there is groundwater extraction, or conversely a reduction in recharge to the groundwater system by the addition of an impervious surface, it is important to understand where one is in the geologic and hydrogeologic setting before potential impacts to land use change and potential mitigation measures can be assessed. In some settings only limited data collection will indicate that

impacts will be minimal while other areas will require extensive data collection depending on the sensitivity of the fisheries habitat and the land use change proposed. It is again noted that because of the strong correlation between fisheries habitat and groundwater discharge, anywhere that potential fisheries habitat exists, then groundwater discharge and recharge areas supplying the discharge water will likely be an important issue.

4.0 OVERVIEW OF POTENTIAL LAND USE IMPACTS ON GROUNDWATER RESOURCES PERTAINING TO FISHERIES

4.1 Introduction

There are many potential land uses which could impact groundwater resources. Obviously all the scenarios cannot be presented, however a number of common land use changes are prevalent in Ontario which can impact the groundwater system and these will be presented and discussed in this section. These examples are not meant to present the many potential hydrogeological scenarios or address all possible impacts but they are meant to stimulate a thought process to better understand cause and effect relationships. The examples are generally divided into three figures, a hypothetical hydrogeological setting, types of potential impacts as a result of land use activities, and types of designs/controls to mitigate potential impacts. The figures presented in this section are taken from "Hydrological impact figures for changing land uses" (Blackport, 1995).

There appear to be four major land use activities which warrant special attention, although general assessments can be applied to all land use changes. The four specific areas of land use changes are:

- 1) Aggregate extraction
- 2) Urban development
- 3) Rural land use
- 4) Groundwater withdrawal

Some overlap exists between several of the areas, in particular groundwater withdrawal as related to the other three land uses. This is kept relatively separated from the discussion of other land uses because assessment of groundwater withdrawal is the same regardless of the land use application. The discussion related to the other three major land uses generally focuses on the impact of the land use activity itself. A brief description of each land use in the context of this document is presented below.

4.2 Aggregate Extraction

Aggregate extraction is often a sensitive issue with respect to potential impacts on fisheries habitat. This is primarily because aggregate is highly permeable, therefore considerable groundwater flow is expected to occur through an aggregate deposit. If the aggregate is in a recharge area there will be considerable infiltration. If the aggregate is

in a discharge area then groundwater may contribute significantly to baseflow. Aggregate extraction has the potential to disrupt groundwater flow.

Typically, extraction of rock (quarrying) below the water table is conducted in conjunction with dewatering (i.e. removal of water to maintain a water level at or below the quarry floor) of the site. Aggregate extraction of sand and gravel below the water table is typically performed by dragline removal of the 'wet' aggregate without dewatering, however this is not always possible and pumping could occur. Pumping at some extraction operations may lead to a partial dewatering of the aquifer and a general lowering of the water table in the vicinity of the extraction. Dewatering the aquifer and lowering the water table can lead to a reduction in stream base flow and losses to wetlands. In some cases, although dewatering does not take place, considerable pumping and recirculation of water takes place for washing operations. This could also affect the groundwater flow system although to a lesser degree. Changes in groundwater flow and hence discharge could occur as a result of this pumping.

Sand and gravel extraction may lead to an overall loss in groundwater storage capacity. Furthermore, if the pits are allowed to fill with water after mining is finished, the water may be subject to prolonged exposure to solar radiation and hence elevated temperatures. If sufficient subsurface travel time to enable cooling to soil temperatures is not provided then discharge water may be unacceptable.

It is noted, with respect to aggregate extraction, that many situations could potentially enhance recharge or baseflow if the groundwater flow is adequately assessed. Innovative design, requiring minimal adjustment to extraction operations may provide net increases in fisheries habitat. Figures 5 through 7 show examples of an idealized hydrogeologic setting, types of potential impacts from aggregate extraction and potential approaches to mitigate these impacts.

Figure 5 describes a hypothetical hydrogeologic setting where aggregate extraction has been proposed. At this site, a relatively low permeability glacial till unit is overlain by permeable sand and gravel. The sand and gravel acts as the aquifer while the till acts as an aquitard to minimize groundwater flow to depth and causes most groundwater to move within the upper unit and discharge in topographically low areas. Note the occurrence of a groundwater fed stream west of the proposed site and the occurrence of a wetland and stream to the east of the proposed site. For the purposes of this discussion it is assumed that the wetland drains into the stream, down gradient of the site, although the setting could range from a headwaters area to a divide between two small streams. Note also the position of the groundwater flow divide. The elevation difference between the water table, in the area of the groundwater flow divide, and the discharge areas (wetland and streams) provides the driving force (hydraulic gradient) required for the groundwater to flow through the sand and gravel strata and into the wetland and streams. In Figure 5, if the permeability of the aquifer was consistent, then more water would be expected to flow westward, to the topographically lower location due

to the greater hydraulic gradient. This is also dependent on the location of the water table divide.

Figure 6 illustrates the hydrogeologic setting presented in Figure 5 after aggregate extraction to some depth below the initial water table. Note how the watertable has dropped with respect to its initial elevation. This reduction in the hydraulic gradient results in a reduction in the driving force required to move groundwater into the stream and into the wetlands. Because of the reduction in the hydraulic gradient the inflow to the wetland can reasonably be expected to be more severely impacted than the inflow to the stream. In effect, the groundwater flow divide is moving to the east, toward the wetlands.

In Figure 6, the aggregate extraction below the water table produced a small lake. The lake water will increase in temperature, and as a result of the recharge processes, so will the groundwater temperature. Thereafter, the temperature of groundwater discharging to the stream on the west may increase, negatively impacting fish and fish habitat.

Figure 7 shows an example of mitigation of potential impacts of aggregate extraction by minimizing the extraction below the water table. In this case, although less aggregate is removed, the groundwater divide and the water table elevation are maintained, and hence the driving force (hydraulic gradient) for the movement of the groundwater is also maintained. Recharge may in fact be enhanced in this case. Washing off-site will minimize the potential disruption to groundwater movement. It is noted that the scale of the extraction and location within the groundwater flow system will indicate the potential for impact. Appropriate baseline studies may show that large scale aggregate extraction could occur in some areas with minimal impact on fisheries habitat and fisheries.

An aggregate extraction operation involving the extraction of bedrock that is below the water table generally requires some sort of dewatering. Consequently, this type of operation has a greater potential impact on groundwater resources. Figure 8 shows an example in plan view of a proposed aggregate extraction area, while Figure 9 shows a west-east cross-section through this hypothetical setting. For purposes of assessing potential impacts the potential aggregate extraction area is located in a relatively flat headwaters area with wetlands north and south of the site draining to a shallow lake to the east (Figure 8).

There is a relatively thin overburden with a shallow water table from which groundwater flows outwards from the area of proposed extraction to the lake and wetland. Flow occurs through both the overburden and through the shallow bedrock. Of importance in assessing groundwater impacts with respect to bedrock is the orientation of fracture patterns in the bedrock. In this case it is assumed a general east/west fracture pattern. This implies a preferred groundwater flow in an east-west direction as it is much easier for water to move along the fractured pathways, assuming there is a reasonable interconnection of the fractures.

Figure 10 shows the potential impacts on the groundwater system as a result of aggregate extraction, with dewatering taking place to maintain conditions as dry as possible in the quarry. Of particular note, relative to Figure 9, with respect to the potential types of groundwater impacts, is the extent of the drawdown as a result of pumping water out of the quarry. In this example the drawdown has extended to below the stream and lake. As a result there is a reversal of the hydraulic gradient, from groundwater discharge to the wetland and lake, to surface water recharge from the wetland and lake to the groundwater zone. Obviously the reversal of gradient results in significant impacts on groundwater discharge areas with respect to spawning areas and volumetric baseflow, particularly in headwater areas as the groundwater discharge is entirely cut off. The change in water movement also affects water quality, as the quality of the groundwater, including temperature, no longer moderates the stream water quality.

The extent of the drawdown or drawdown cone can be seen in the plan view example in Figure 11, with an elliptical shape elongated in the direction of the main fracture patterns. Depending on the extent of this drawdown, the impact can be major or very minor. This example showed a major impact as a reversal in groundwater discharge occurred due to the reversal of the hydraulic gradient. There are many situations however, where rather than a reversal in gradient there is merely a sufficient lowering in water levels 'driving' this gradient that discharge is reduced, as an upward gradient still exists. The actual impact on fish habitat will be difficult to quantify in these situations, however the extent of reduction in discharge or baseflow could be quantified. Although quarrying below the water table typically results in considerable pumping of water or dewatering, there are several controls that can be utilized to minimize potential impacts of quarry dewatering. Figures 12 and 13 show an example of this.

Figure 12 shows that the direction of quarrying can affect the quantity of water moving into the quarry at any one time. In this case if quarrying proceeds parallel to the main fractures then the rate of groundwater movement into the quarry will be minimized, as fractures that transmit the water are progressively exposed rather than starting by taking a north-south cut and exposing all the fractures at the commencement of quarrying.

The figures also show berms in place on the east and west side of the quarry that create ponds to maintain water levels outside the quarry area. The viability of berms and ponds will depend on the qualities of the fractured rock with respect to leakage through and under the berms. If excessive recirculation of water is necessary to maintain water levels in the ponds this technique may not be viable and other technical solutions should be considered. The potential also exists for impacts on water quality. In this example, possibly the deeper groundwater entering the quarry contains high sulphate or iron concentrations, which may be recharged into the shallow groundwater zone through leakage from the upper portion of the pond. Different potential aquifer 'units' within the bedrock should be assessed to determine where the majority of groundwater flow may originate (i.e. which unit) and if this is hydraulically connected to surface waters. This example is presented to show that the potential does exist to mitigate the groundwater

impacts in certain settings if there is a sound understanding of groundwater flow. In most cases extensive investigations would likely be required to gain this level of understanding of groundwater flows.

The next example, as shown in Figure 14, is to highlight the regional hydrogeologic setting and, although not shown here, to understand the potential for cumulative impacts from several quarrying operations. Figure 14a shows a classic regional flow system with a major recharge area and groundwater divide between two regional discharge areas. Figure 14b shows a major quarry operation and the resulting dewatering shifts the groundwater divide to the west. As a result, there may be a long term decline in the recharge area that maintains the discharge in the western watershed as the 'recharge area' has now decreased in size.

Since the additional water is pumped out of the quarry and discharged to the surface there is also a net groundwater loss to the eastern watershed. Depending on the presence of other aggregate operations, which is often the case in areas where good quality aggregate exists, there may be a cumulative decline in the recharge to the groundwater system and this should be examined on a regional scale.

4.3 Urban Land Use

Urban land use is being defined in this document as land use changes related to growth or expansion of existing urban areas that are fully serviced although this growth may occur in what is presently a rural area.

As urbanization progresses within a watershed, certain events typically occur, leading to degradation of streams in a more or less predictable fashion. This is because historically the prime focus of water management in urban areas has been to either move or control the storm water to minimize flooding and erosion, with little emphasis placed on infiltrating stormwater which would have naturally infiltrated under pre-development conditions. Best Management Practices (BMP's) related to storm water management have changed substantially over the last 5 years, to reflect the needs and benefits from infiltration. The conventional process of deterioration (urbanization 'syndrome') characteristically includes the following events:

- A) Reduction in tributary density, particularly in headwater areas. Small headwater tributaries are frequently eliminated or altered radically when the land is drained, when streams are placed in pipes to maximize flood and erosion control, or when they are paved over to increase the amount of developable land. Many headwater tributary streams have important roles in the discharge stability of watersheds (and are frequently the receptors of significant amounts of groundwater discharge). Moreover, the cool, clean, stable flows in these streams provide critical spawning and nursery habitat for sensitive fish species.

In southern Ontario, the native brook trout is virtually restricted to what remains of these habitats.

- B) Use of impervious surfaces (e.g. pavement for roads and parking lots, and roof tops) increases the amount of peak surface runoff and decreases the portion of precipitation that soaks into the soil to recharge the groundwater system. Topographic changes such as earth fills related to the construction of roads, drainage ditches, driveways and houses can result in a significant loss in storage depression capacity and infiltration. Under these circumstances the overland flow portion increases, leading to increases in the frequency and magnitude of storm events and peak discharges. Ultimately, this can lead to reductions in baseflow, reductions in channel and floodplain complexity, and impaired water quality (Steedman 1988; Steedman, 1987; Imhof et al., 1991). The net result of these modifications are structurally simplified river channels containing little physical diversity for aquatic biota. Profound changes to the fish community can occur as the amount of habitat for sensitive species is altered, reduced or destroyed.

Considerable work has been performed with respect to storm water management and the infiltration of storm water. In assessing potential impacts on urban development, innovative storm water management should be aggressively pursued. There are many techniques which should be considered, such as infiltration trenches to grass swales, filter strips, dry wells, and the replacement of lost storage depression capacity. The focus under suitable conditions should be to have as much at source infiltration as possible. Due consideration should be given, however, for the potential negative effects of storm water controls of these types, particularly, water quality and supply concerns.

Figures 15 through 17 show an example of an urban land use setting change, and the potential approaches to minimizing impacts. Figure 15 shows a typical 'fringe area' development proposal, adjacent to an existing urban area. Water courses run through the developed area, however, the area for proposed development contains many small tributaries feeding into larger streams. The cross-section indicates the existing development does maintain some of the baseflow to a 'protected' wetland stream area (protected only by virtue of a buffer). The proposed development area is a recharge area that maintains baseflow to local tributaries, maintains recharge to intermediate level areas such as the main tributary in the developed area and can also maintain regional flow. Changes that can occur in the existing developed area related to groundwater/surface water interactions include:

- decreased infiltration resulting in decreased recharge to the groundwater, hence less groundwater to maintain baseflow;
- increased opportunity for degradation of groundwater and surface water quality;

- increased sedimentation of stream channels potentially resulting in a decrease in groundwater discharge (i.e. 'blocking' upwelling);
- increase in surface water temperature resulting in even more importance being placed on groundwater discharge or baseflow to moderate stream temperature;
- potential lowering of the water table or cutting off discharge with service trench excavation into the water table, whether permanent or seasonally high water level.

Further development, as shown on Figure 16, could result in greater impacts than those described above. The area of proposed development is more sensitive as it is closer to headwater areas for numerous small tributaries as well as being an important recharge area. Depending on the linkage of the recharge area to the components of the ecosystem, potential impacts may be local, regional or both. As a result potential short term and long term impacts can occur unless proper management practices are in place for storm water management.

The key aspects of potential impacts of development related to Figure 16 are:

- 1) the potential loss of baseflow and direct discharge to the local tributaries, in this case headwater areas;
- 2) potential for sedimentation in the local tributaries and subsequent decrease in baseflow and change in water quality;
- 3) decreased infiltration to the recharge area for the intermediate level stream and associated wetland; and
- 4) potential long term decrease in recharge to the regional flow system.

Figure 17, although not detailed, indicates that a number of options exist with respect to better controlling and managing storm water in order to maintain recharge conditions. This may range from at source infiltration from roof tops, driveways, etc., to large scale infiltration ponds. From a groundwater perspective, to approach to maintain recharge as close to pre-development conditions as possible, depends on the location of the development within the hydrogeologic system and its linkage to the discharge areas. The more localized the connection of the recharge/discharge area, the more critical the source storm water controls, and it will be difficult without an extensive investigation to determine the exact linkage between zones within the discharge area and the recharge area. The closer proximity the recharge area is to a discharge area the more direct control the recharge area will have with respect to the discharge area.

With greater distance from the discharge area, stormwater being recharged to the groundwater system can be maintained by a variety of controls, however as shown in Figure 17 there may be a number of groundwater flow paths so it would be important to ensure the water is being recharged to the appropriate part of the flow system, both with respect to quality and quantity considerations.

The following general aspects should be taken into consideration, from a groundwater perspective with respect to stormwater management practices:

- 1) understanding where the development is in relation to the flow system (i.e. local, regional);
- 2) depth to the high water table, as this will affect the ability to utilize certain stormwater management controls. For example, if the water table is shallow it may be difficult to utilize large infiltration galleries. Alternatively, if the reason for the shallow water table is that this portion of the development is a discharge area (e.g. the base of the hill in the new development area, Figure 17) then infiltration in this area may not be appropriate.
- 3) permeability of the geologic material above the water table. If the material is fine-grained then infiltration capacity will be limited with respect to putting stormwater back into the ground. As well, if fine-grained geologic material is present then the sensitivity of the area with respect to recharge will be low.

4.4 Rural Land Use

Rural development is being defined in this document as development occurring outside urban areas either serviced privately or communally with respect to water and sewage. This includes developments such as estate residential subdivisions and cottage and condominium development on lakeshore/river properties. The potential impacts are similar to urban development but generally on a smaller scale, however there may be more opportunity for land impacts. Potential impacts are also related to water taking (discussed in the next section) and wastewater effluent discharge from septic systems, in particular nitrate in water directly discharging to streams.

Other aspects of rural land use, which are important, are related to agricultural activities which, could have significant impacts on both water quantity and quality. The main issues related to groundwater are: groundwater withdrawal for irrigation (discussed in the next section); nitrate loading to the groundwater and subsequent potentially elevated nitrate concentrations in groundwater discharging directly to streams; and sediment loading to stream beds resulting in decreased baseflow and direct discharge. Although often overlooked in rural development proposals, in some settings the impact of the

development may be less than the impact of the present agricultural operations. In other words Best Management Practices (BMP's) in a development setting may be better than poor management practices in a rural setting, and innovative management practices should be pursued whenever conditions warrant it.

Figure 18 shows various types of conditions which may occur in a rural setting. Figure 18a shows a plan view setting indicating agricultural activities adjacent to a stream course and an area of proposed residential development. Figure 18b shows a cross-sectional view of the same area indicating local recharge and discharge. Figure 19 shows examples of potential impacts from rural land use activities. On the east side, where agricultural activity is on-going, the runoff from the ploughed fields can quickly enter the stream course as there is not an adequate buffer along the stream. This could result in sediment loading to the stream potentially cutting off discharge into the stream (as well as other impacts unrelated to groundwater). The water quality of the infiltrating water may be impaired by the addition of fertilizer's and pesticides from agricultural activities. The extent of this type of impact depends on many factors such as depth to water, organic carbon content of the saturated material, length of travel etc. The best method to assess impacts is to assess the quality of the water discharging to the stream. Alternatively the woodlot would act to impede overland flow, promote infiltration of good quality water and minimize sediment loading to the creek. This woodlot however, and part of the agricultural area on the west side of the stream are being developed and serviced by individual wells and septic systems. As a result, potential impacts that could occur include: loss of infiltration based on increased runoff in the former woodlot area; loss of infiltration as a result of increased imperviousness in the developed area; changes in water quality as a result of septic effluent; and the potential for spills within the development area.

Some of the potential ways to mitigate impacts are shown in Figure 20. With respect to the agricultural areas, several types of changes can impact groundwater. The most obvious are: 1) change in tillage direction if possible to minimize overland flow as this maximizes infiltration and minimizes overland flow and sediment loading to the stream; 2) creation of a buffer strip to minimize direct overland flow and sediment loading to the creek (HSP Inc., 1992); 3) minimize fertilizer application during periods of high runoff (Ontario Ministry of Agriculture and Food et. al. 1976) and; 4) conduct soil nutrient assessments to determine the appropriate amount of fertilizer applications, given the existing conditions.

With respect to rural development the same controls are applicable as discussed for urban development in the previous section for maximizing infiltration, in particular, at source. The prime difference, compared to urban development, is related to septic effluent, quantity and quality. From a quality perspective, nitrate loading appears to be the prime concern although phosphorus is also a potential concern. As stated previously the impact of nitrate on groundwater moving to the stream depends on various factors such as depth to water, organic carbon content, dissolved oxygen etc. Considerable

research has been conducted in this area recently (e.g. Robertson et. al., 1991) as well as in the area of phosphorus mobility (Sawhney, 1977; Sawhney, 1975; Whelan, 1984).

One aspect often overlooked in the assessment of potential impacts of developments with septic systems is the potential difference in nitrate loading pre and post development with respect to agricultural versus septic loading of nitrates. In many cases the agricultural contribution may be significantly greater than estate residential type development. In fact, in some cases the nitrate loading and the additional water from septic effluent, if water filter wells were constructed in a deep aquifer, would in fact enhance baseflow.

If septic effluent was a concern, alternative septic systems are now more common place, whereby the nitrate concentrations entering the groundwater system are significantly reduced. Class 6 systems are regularly used and alternative technology such as peat filter beds and aerobic biofilters help to reduce nitrate concentrations.

Another component of rural land use, more prevalent in northern Ontario is related to vegetative changes. Vegetative changes are defined as alterations to the vegetation type of a drainage area of sufficient magnitude to potentially alter the water balance. This is primarily related to forest clearing, either for logging or agricultural purposes. The effects on the water balance could be positive or negative from a fisheries perspective depending on the topographic relief, vegetative ground cover (i.e. grasses, shrubs) and soil type. For example, in northern Ontario a 'clear cutting' type approach to logging on a hillside may significantly increase runoff and decrease groundwater recharge as the water may not be 'trapped' sufficiently to allow infiltration.

Alternatively, in areas cleared for agriculture, an increase in grasses may increase the ability of the soil to infiltrate 'trapped' water while at the same time keeping more water available to infiltrate due to decreased evapotranspiration.

4.5 Groundwater Withdrawal

Pumping groundwater from aquifers is frequently done to supply water for a variety of uses. Some cities and towns create large well fields for domestic supply, and increasingly, rural developments are utilizing communal well systems to service them. Agricultural practices, golf courses, sod farms, nurseries and greenhouses are all known to use significant amounts of groundwater for irrigation.

Withdrawals of too much groundwater from an aquifer can potentially lead to reductions in stream baseflow and direct discharge, which are important for maintaining the quantity and quality of fish habitat. Furthermore, over use of groundwater can lead to the lowering of the water table which can negatively impact wetlands in the surrounding area. As wetlands are important fish habitat, any disruption of groundwater discharge patterns that lead to the harmful alteration or destruction of wetlands will lead to attendant losses in

fish habitat.

Figures 21 and 22 show a complex geologic cross-section and various groundwater withdrawal scenarios that could occur in this setting. Although this example cannot cover all of the different geologic settings, it provides examples of typical situations. Figure 21 shows local, intermediate and regional groundwater flow controlled primarily by topography and the geologic setting. Of note are the following:

- the local wetland controlled by a low permeability till in the western upland area;
- local wetland and discharge areas near the valley bottom;
- groundwater flow and discharge in the eastern upland area controlled by the extensive underlying low permeability till;
- flow from the shallow aquifer to an intermediate and deep aquifer;
- the low permeability till below the shallow aquifer underlying the stream acts to help control discharge to the stream.

Figure 22 shows four potential locations of pumping wells which could result in variable impacts on the groundwater system. Well 1 would result in the local drawdown of the water table with potential impacts on the wetland area located above the well and possible discharge areas along the valley side, impacting baseflow.

Well 3 is also located in the shallow aquifer, but closer to the valley bottom and the stream. Pumping in this location could substantially reduce the discharge of water to the stream, reducing baseflow or possibly even reversing the gradient from upward to downward, effectively utilizing the stream to contribute to recharging the aquifer locally.

Well 2 is located in an intermediate aquifer below the valley bottom/streambed area. The degree of impact from pumping this well will depend on whether the drawdown of the water levels extends through the 'window' in the low permeability till unit (aquitar), sufficiently deep enough to interrupt water discharging to the stream.

Well 4 located in the deep regional aquifer would likely have no significant impact on groundwater discharge given the thickness of low permeability till and the distance to the 'window' in the aquitar.

In situations involving groundwater withdrawal, the most appropriate approach to protection is to prevent or minimize the impacts by conducting properly monitored pumping tests to assess the response of groundwater levels to the pumping. This will be discussed in more detail in the last sections of this document.

4.6 Summary

The previous section presented a general overview of several land use potential impacts on groundwater resources, using examples from different hydrogeological settings. The section was not designed to be exhaustive, as the number of variables associated with land use changes and the different hydrogeological settings preclude a presentation or description of all possible scenarios. However, the section was designed to present examples of typical land use changes under several hydrogeological conditions in order to better understand how one might approach an assessment of a particular site, especially in the absence of any watershed or subwatershed plan. It is expected that strategies could be developed to assess the potential impacts of a particular land use change as knowledge is gained with respect to the linkage between fisheries habitat and groundwater flow and the function of the land in question in maintaining this linkage. A better understanding of groundwater flows, hydrogeologic settings, fish habitat, and groundwater - fish habitat linkages, will lead to an increased ability to predict and mitigate potential impacts or even enhance the function of the land. The next sections deal with a general approach towards the development of a logical assessment of potential land use impacts based on what has been defined as key functions of groundwater for maintaining fisheries habitat. The hydrogeologic setting for the land in question maintains these functions, and so the proposed decision flow chart framework, which is discussed in Section 5.0 (Figures 23 and 24) identifies these as areas for concern and protection.

5.0 GROUNDWATER PROTECTION STRATEGIES

5.1 Introduction

There is currently limited enforcement of protection policies for the aspects of groundwater functions important to fisheries habitat. Because of the inter-disciplinary nature of the problem, there is generally a limited understanding of the issues, often resulting in cursory assessment of the potential impact of a particular land use activity. As stated previously most 'protection' of groundwater is related to major water extractions through the Ontario Water Resources Act and groundwater quality through the Environmental Protection Act. It appears that one of the few approaches to protecting and maintaining fisheries habitat, with respect to groundwater concerns, is through Section 35(1) of the Federal Fisheries Act (i.e. no net loss of fisheries habitat). In order to develop a strategy for groundwater protection there must be an understanding of the issues as presented in Sections 2 and 3. If the underlying premise is no net loss of fisheries habitat then a groundwater protection strategy statement would need to take into account what percentage reduction in baseflow or gradient would result in an unacceptable impact on fisheries habitat, as this is the controlling factor. From a water quality perspective it would be difficult to say no net change in water quality. It is also difficult to establish water quality or quantity targets or thresholds for individual land use changes as it is unknown what other changes may occur within the groundwater or surface water system. In other words, the cumulative impacts need to be assessed at a sub-watershed or watershed scale before targets or limits can be set at a local scale. Without this knowledge the safest approach is no net change, however, this approach minimizes opportunities for enhancement in areas where enhancement is suitable. Although inter-related the following factors are deemed to be the critical components of groundwater flow/water balance related to fisheries habitat:

- 1) baseflow from the regional groundwater system (long-term sustained flow)
- 2) baseflow from local groundwater flow
- 3) direct groundwater discharge to the stream bottom (upwelling)
- 4) stream water temperature
- 5) groundwater quality
- 6) storm water runoff

Assessment of the quality of the fisheries habitat within any stream can help determine how critical these components are in sustaining the fisheries habitat. What cannot be determined however is the impact the land use changes will have on these components

unless a certain level of study is performed. The level of study will depend on the complexity of the geologic and hydrogeologic system, and where a particular area is within the groundwater flow system/hydrologic cycle. A cause and effect relationship must be performed through baseline investigations designed to determine potential impacts of land use changes and ways to mitigate these changes.

Studies have to be designed to address the critical components. The design is obviously based on several factors which may not be known until a certain level of study is completed. Factors which need to be assessed include:

- 1) the quality and scale of the fisheries habitat or potential habitat
- 2) the complexity of the geologic and hydrogeologic setting
- 3) the type and magnitude of the proposed land use changes
- 4) the types of impacts anticipated from the proposed land use changes
- 5) the ability to mitigate potential impacts

Until a certain level of study is performed it cannot be determined whether detailed studies are required to adequately address the potential for impacts. An iterative approach is proposed initiating a baseline level of study for various land uses and developing an assessment procedure to determine whether the information is adequate or more investigation is required. The approach should streamline the process so that if there is limited potential impacts then this is quickly determined (with minimal cost) and the project can be given the 'green light' from a fisheries perspective.

If concerns are raised through the preliminary study, then the framework is used to determine what issues need to be addressed in more detail at an early stage. This accomplishes two things, it allows a proponent of the land use change to logically develop a study plan and know what decisions may be made at key times in the process and it allows reviewers an ability to maintain a 'check and balance' as the study progresses and more knowledge is gained.

This section deals with the development of a decision flow chart to aid in streamlining the process.

5.2 Decision Framework and Flow Chart

Figure 23 shows a flow chart indicating the general framework in which to assess the potential for impacts and the level of detail required to perform the assessment. This general framework is presented in more detail in Figure 24 and Tables 1 and 2. An

overview of the general framework is presented below, prior to the detailed discussion.

5.2.1 Assessment of Existing/Potential Fisheries Habitat

The initial question to be answered prior to conducting detailed analyses is whether or not there is existing or potential fisheries habitat that could be affected by land use changes. There must be some knowledge of the fisheries habitat adjacent to the particular area. If no fish habitat exists in the adjacent area, the site impact at a local scale may not be a concern. Conversely, some understanding of the land area and potential relationship of function to regional, larger-scale flow, must be assessed to determine downstream larger scale impacts. If little potential concern is noted then no further investigation is required (Figure 24).

If fisheries habitat impacts are a concern, then two types of assessments are required for the area in question. The first assessment: "Potential Fisheries Related Groundwater Impacts from Changing Land Use Activities" is required to determine the sensitivity or risk of potential land use activities on groundwater maintenance of fisheries habitat. The second assessment: "Hydrogeological Setting" of the land area in question is required to determine the functions performed by groundwater in maintaining fisheries habitat.

These two assessments need to be evaluated in a logical manner to determine the level of risk/sensitivity that will allow the development of appropriate land use controls/restrictions, management practices and monitoring. Figure 24 deals with these issues in more detail.

Figure 24, combined with Tables 1 and 2 provide a more detailed screening and level of effort of the study requirements to adequately assess the potential impacts of land use changes on fisheries habitat. The following section describes in detail the various components of the Decision Flow Chart, with the emphasis on the first four components. A complete understanding of these components is required in order to make appropriate decisions for the later components in the flow chart.

5.2.2 Initial Screening: Assessment of Fisheries Habitat Attributes

As mentioned previously the key screening in the beginning of the process should ask: Is fisheries habitat present that requires protection? This is really a three-part assessment:

- 1) existing fisheries habitat in the adjacent streams
- 2) potential or degraded fisheries

3) potential support of baseflow which in turn may be required for downstream fisheries

In areas where watershed or sub-watershed plans have been developed there may be considerable information available to minimize the level of effort required for the initial screening, however local site specific assessments may be required to supplement the subwatershed plan data.

In the absence of subwatershed plans, both site specific data and regional scale data may be required, in particular downgradient of the land area in question.

In the context of this document existing fisheries habitat means areas where fish species have been identified. Potential fisheries habitat means the attributes exist that provide the potential for fish, although no species have been positively identified. This potential is often based on appropriate groundwater/baseflow conditions being present along specific reaches of the stream. In many systems, fish species have been eliminated by land use practices which may no longer be present.

A particular area may also have the potential to support recharge to downstream baseflow which may provide adequate flow/temperature conditions to support fisheries habitat. If no subwatershed plan is in place a more detailed assessment may be required than an initial screening, however if a cursory assessment of the data indicates limited recharge potential then further investigations may not be required.

If the initial screening indicates that the attributes of fisheries habitat are present then a Level 1 assessment is required for both land use impacts and the potential function of the hydrogeological setting for the land area in question. Tables 1 and 2 provide details of the two areas of investigation for a Level 1 assessment. These two areas of investigation are discussed in the following two sections.

5.2.3 Level 1 Assessment: Potential Fisheries Related Groundwater Impacts from Changing Land Uses.

In order to assess the potential groundwater impacts an understanding of the impacts of land use or land use change on the function of the groundwater from the land area in question must first be developed. This must then be integrated with the hydrogeologic setting to determine how sensitive or critical this change in function is (based on the hydrogeological linkages of the land area) to the fisheries habitat.

Table 1 shows a matrix of the most common land uses versus the potential types of groundwater impacts for these land uses. The potential sensitivity of impacts (low medium and high) for the four types of groundwater functions are also identified. The four functions categorized in this document are:

- volumetric baseflow
- direct discharge
- water quality
- recharge

Volumetric Baseflow: In this document volumetric baseflow is the groundwater contribution to baseflow which maintains the actual volume of baseflow in a stream critical for quantity and temperature (thermal control). This could include direct discharge, discharge to wetlands, continuous or seasonably sustained bank seepage, hill slope seepage, etc.

Direct Discharge: Although critical in sustaining baseflow, direct discharge is more critical for maintaining spawning areas, supporting redds, and creating thermal refugia. This is commonly referred to as areas of upwelling. This discharge can be from local or regional flow, however, when direct discharge is interrupted by land use patterns, the impact is usually a local scale linkage.

Water Quality: The potential impacts related to quality are mainly temperature related from a groundwater quantity perspective, however, quality related to such parameters as dissolved oxygen, ammonia, nitrate and phosphorous are also critical. The potential impact on water quality from the various types of land use changes must be assessed.

Recharge: Although recharge is the driving force for discharge, it is treated separately. From a land use perspective, recharge will be affected primarily by decreasing the perviousness of an area or 'flattening' an area to minimize infiltration from surface water ponding. The degree of impact will depend on the hydrogeological setting. In some cases there may be potential local impacts while in a regional setting the potential impact may not be noticeable for a long period of time, or may be cumulative with other land use changes.

Table 1 presents a general ranking of the sensitivity of groundwater impacts for various land use activities versus different groundwater 'categories'. The following examples are presented to indicate the basis for selecting the various levels of sensitivity. Under the land use category "Aggregate Dewatering", which would primarily be related to quarrying, the potential exists for high degrees of impact on volumetric baseflow, direct discharge and recharge, while moderate for water quality (primarily temperature related). The actual hydrogeological setting would then have to be assessed in detail, and given the potential for impacts, the onus would be with the proponent to show that the hydrogeological conditions will not result in significant impacts, or that the impacts can be controlled or mitigated through appropriate measures.

Within the land use category of "Rural Development" there are several categories which will have varying degrees of potential impact, depending on the servicing and engineering controls. For example a rural development on individual wells is expected to have a generally low impact, because the quantities of water removed from the flow system are typically low. This does not mean an impact may not occur under certain hydrogeologic conditions, however the potential is low. The potential for impact, utilizing communal wells, becomes much higher given the concentrated removal of water from one area. Because the potential is high, the hydrogeological setting must be assessed in more detail.

As indicated from the above discussion, the potential land use impacts must be assessed in conjunction with the hydrogeological setting to determine whether the setting is such that the potential impact is highly likely or unlikely. If it is unlikely then only limited additional work may be required. If the potential for impacts is likely at this level of hydrogeological detail, then a more detailed assessment will be required.

5.2.4 Level 1 Assessment: Potential Function of the Hydrogeological Setting.

Table 2 shows the sensitivity of the groundwater functions under different hydrogeological settings. The same groundwater categories are utilized in this table as in Table 1, to compare the sensitivity of the potential impacts.

In this document the hydrogeologic setting has been divided into two major settings, an "Aquifer" and a "Non-Aquifer" setting. The hydrogeologic settings were divided into "Aquifer" and "Non-Aquifer" settings because there will be settings where an 'Aquifer' does not appear to exist or to be usable but the area may contribute to any one of the groundwater functions. The aquifer setting is divided into three major categories (Unconfined; Semi-Confined; Confined), primarily on the basis of how these settings help to maintain the groundwater functions shown in Table 2. Unconfined aquifers have the ability to provide significant recharge to the groundwater system, on both local and regional scales, as well as providing good hydraulic connection to the discharge area, on both local and regional scales.

Confined aquifers are expected to contribute little to the groundwater function related to fisheries, because by their very nature they are 'Confined'. Even if these aquifers are pumped and the movement of water in or out of the aquifer is reversed by pumping, this movement is small. There may be settings however, where the 'Confining' layer is moderately permeable or there are 'windows' or breaks within the layer as a result of certain geologic processes. The aquifer could then be considered to be 'Semi-Confined' and the potential exists under certain types of land uses to impact groundwater flow or quality.

In some areas, particularly discharge areas in valley floors, an 'aquifer' may not appear

to exist, based on location of water wells, geologic descriptions, etc., however, there may be sufficient discharge on the basis of the topographic/geologic setting that this water provides important contributions to baseflow. This may be most evident on the basis of fisheries habitat assessment. If fisheries habitat exists in a particular reach of stream but no apparent 'aquifer' unit is present to create good discharge conditions, then obviously there must be a sufficient contribution of groundwater to maintain this habitat.

Table 2 shows the relative sensitivity of the potential function of the four groundwater categories versus the different geologic settings. Emphasis is placed on the potential function of groundwater in a particular hydrogeological setting, as related to fisheries habitat. At a Level 1 detail of study it may be difficult to determine the hydrogeological setting, however, the importance of interpreting the setting will depend on the potential sensitivity and the proposed land use change. For example, if it has been determined that the hydrogeological setting is an unconfined aquifer where the sensitivity for potential impacts on groundwater functions are generally high, then the level of detail for interpreting which hydrogeological setting within an unconfined aquifer is applicable will depend, to a large extent, on the actual land use and potential impacts of the proposed land use change.

If the land use change included private wells for an urban hamlet for example, then there is generally a low potential for impacts and although this does not preclude performing more detailed assessment, it would minimize the level of detail of study. In this particular case the greatest potential for impact is on volumetric baseflow; which may be moderately sensitive, depending on the setting. The potential groundwater function in Table 2 shows a high degree of sensitivity for most types of unconfined aquifers. The focus of study would then be to resolve this issue, given that most developments would have limited impacts on the function of a regional recharge area compared to a local discharge area. The cumulative effects on a regional system may have to be addressed through a watershed or subwatershed plan.

In the case of development of communal wells, whether urban or rural, there is a high potential for impacts on the groundwater resources, in particular, volumetric baseflow and direct discharge (Table 1). There is also, generally, a high to moderate sensitivity for impacts on volumetric baseflow and direct discharge for most hydrogeologic settings, except in confined aquifers and in low permeability areas. As a result there would have to be sufficient data available in a Level 1 study to adequately determine the hydrogeological setting of the site to determine conclusively that these conditions exist. If this is not the case then more detailed studies would be required, of which the level of study and primary objectives of the study will be dictated by the sensitivity of the potential impact (Table 1) and the hydrogeological setting (Table 2).

5.3 Summary

The above discussion presents examples of the approach for using Tables 1 and 2 to determine whether a Level 2, detailed hydrogeological investigation, is required. Where a detailed Level 2 assessment is required, it is critical to perform an appropriately detailed hydrogeological investigation to fully characterize the relative risk of the proposed land use relative to the hydrogeological setting in order to provide meaningful input into the decision making process for the remaining components in Figure 24. Without these detailed assessments, the hydrogeological setting and relative sensitivity of the groundwater functions would not be understood, and proper controls/constraints and monitoring programs cannot be developed and put into place.

6.0 ASSESSMENT OF POTENTIAL IMPACTS OF LAND USE CHANGES ON GROUNDWATER RESOURCES AS RELATED TO FISHERIES HABITAT

6.1 General Information Requirements

The following general approach is proposed for assessment of potential impacts from land use changes with respect to groundwater and fish habitat issues. It must be kept in mind that these issues are very general in nature and that the answers to the various questions will range from very simple answers with no data collection to very complex answers involving considerable data collection. The answers will obviously be a function of the sensitivity of the physical geological/hydrogeological system and the fisheries habitat as they are inter-related. Appendix A provides examples of the types of data which may need to be collected to answer some of these questions, and as discussed in Section 5.0, a flow chart is presented in Appendix 2 to provide the general frame work for the approach to assessing land use impacts.

There are a number of general questions that can be asked for any type of land use change at a baseline level of study. Answering these questions can resolve or raise concerns regarding basic groundwater issues and fishery habitat. In other words there are a minimum number of questions which need to be answered in order to determine whether a greater level of study is required. This section develops the 'questions' to be answered in, relation to what should be investigated, in order to 'fine-tune' the determination of the hydrogeological setting or function of the groundwater. This approach not only allows a determination of whether a Level 2 assessment is required, but also streamlines the approach to the study.

The Level 1 detail can usually be obtained by utilizing existing published information and minimal site specific studies often performed as part of most land use assessments (i.e. test pits, boreholes, assessment of depth to water, grain size analyses etc.). The factors which trigger a level 2 study can usually be determined quickly once this baseline assessment has been conducted. This will either quickly rule out sites which do not require more detail or determine the type of studies and potential concerns/mitigative measures, etc., required. In order to determine the impact of land use changes, the fisheries habitat must be assessed as well as the controlling physical conditions related to the geological setting and groundwater flow. The type and magnitude of the impact of land use changes and potential mitigative or enhancement measures can then be evaluated.

The approach to determining the information requirements for the baseline or Level 1 studies is to divide the assessment into the following four categories:

- 1) fisheries habitat assessment

- 2) operational
- 3) pre-development site conditions (physical assessment)
- 4) post-development impacts and site designs/controls

Fisheries Habitat Assessment

It is assumed that the fisheries habitat assessment has been conducted by OMNR personnel or that at least OMNR has a reasonable expectation of the fisheries habitat potential in surface waters of concern. As stated previously the more sensitive the natural system the greater the likelihood that a higher level of study will be required. Even if OMNR personnel have a limited understanding of hydrogeological studies and groundwater/surface water interactions is it safe to assume that if there is a reasonable expectation that there is an existing or potential coldwater fisheries habitat then there is also a reasonable expectation that this is based on the existing hydrogeological setting and therefore the questions should be properly addressed.

The fisheries habitat assessment, from a groundwater perspective could make use of the following:

- In addition to habitat assessment or if it is lacking, evidence of brook trout spawning in or near the area of concern would indicate an active groundwater discharge area that must be examined.
- Often a sign of groundwater intrusions in the winter is the absence of anchor ice in some riffles of a stream and not in others. Groundwater discharges usually prevent the formation of anchor ice on the bottom of riffles in the winter.
- As a corollary of the above, concentrations of trout in small pockets in the middle of the summer during high temperatures is also a strong evidence for groundwater discharges.
- Aerial thermographic data may be available for certain sections of the province. This information can also indicate areas of groundwater seepage into the channel both in the winter and summer.
- A component of the Stream Habitat Assessment Methodology is the identification of seepage and flows of springs out of the banks as a #/100m unit. This information could be very valuable in determining active groundwater areas.

The other 3 categories should be addressed by the proponent of the land use change in a logical manner to answer the general questions presented below. These general

questions should be presented to the proponent as early as possible to optimize the time and expense of the study for all parties. Each of the three components is discussed below in relation to requirements for a baseline (Level 1) study.

Operational

The operational component of the study is basically a series of questions designed to determine what type of operations or alterations are related to the land use activity. Obviously these questions can be detailed for each type of land use change and questions specific to the common land use changes discussed in these guidelines are presented in their specific sections.

Questions about the operations or alterations are designed to determine the following:

- What is the size of the operation/land use?
what area is being considered, will it all be altered at once, or in stages and over what period of time?
- Is it permanent or temporary?
i.e. development is permanent, but the process of aggregate extraction is temporary
- Will there be construction and construction related concerns?
i.e. will there be impacts from construction (sediment control) and if there is construction or alteration over a long period of time does this become more of an issue than the actual impact of the land use change.
- Will construction or land use activity affect the water balance?
i.e. will ground contours change, imperviousness increase, water extraction take place, any major vegetation changes etc.?
- Are there surface water courses on-site or adjacent to the site that will be affected?
- What existing regulations or agencies will control the proposed land use activity and will they address potential concerns related to fisheries habitat?
i.e. who has the jurisdiction over the changes and what ability is there to address fisheries concerns at the provincial level, regional level or municipal level?
- Will there be other potential land use changes in the area which may result in cumulative impacts?

e.g. if it is aggregate extraction will there be potentially more licensed area or if it is development, will the rest of the water shed or subwatershed be developed?

Pre-Development Site Conditions (physical assessment)

It is critical to obtain a base level understanding of the existing physical setting at and adjacent to the area where land use changes are proposed. As stated previously the level of understanding of the physical setting will be proportional to the type of land use change (as determined from the operations component) and the sensitivity and proximity of the fisheries habitat (as determined by OMNR personnel).

Basic questions to be addressed in the physical setting assessment include the following:

- Is there potential fisheries habitat on site or adjacent to the site?
- What is the general geologic setting?
e.g. is it sand, clay, layered units, outwash, till etc.?
- Where is the site in relation to the regional groundwater flow system?
Is it in a regional discharge area, local discharge area, local recharge etc.? As stated previously the importance of the regional system will serve to maintain long term sustained baseflow while local recharge areas serve to enhance baseflow volume but also create areas of direct discharge (or upwelling).

These questions form the basis of understanding the site setting as presented in Table 2, and should be addressed in this manner to understand the potential groundwater function of the site.

- Has a general water balance calculation been performed for the site under present (pre-development) conditions? This needs to be compared to post-development conditions (next section). The level of detail will be related to the sensitivity. It is likely that in critical areas, a more detailed level of study will be required to better define the parameters.

Post-Development Impacts and Site Designs/Controls

Post-development conditions need to be addressed at a baseline level with the level of detail required again proportional to the land use change and sensitivity/scale of the fisheries habitat or potential habitat. As with the physical setting, an understanding of post-development conditions and mitigation measures of potential impacts will indicate

whether or not the proponent has an understanding of the issues related to fisheries habitat.

6.2 Summary

The questions asked in this section should be asked in conjunction with other questions designed to address specific land use changes or hydrogeological settings such that the screening approach in Section 5 can be adequately conducted. This is particularly important in areas where a watershed or subwatershed plan does not exist. As these questions are being asked during the initial screening process, the scale of the hydrogeological system (i.e. local or regional) to be assessed will become more obvious and the level of study required to address potential impact concerns will become more focused.

7.0 SUMMARY

This paper provides one approach to the management of groundwater for the protection and enhancement of fish habitat. The approach is provided as a tool for managers, for the determination of potential impacts or changes to fish habitat resulting from changing groundwater characteristics based upon land use activities. Although the paper focuses on site level activities, we acknowledge that a better approach would be to use this information in conjunction with data and information derived from a watershed and subwatershed study. Given that these types of studies are often not completed or may not be done for some time in many watersheds, this approach is presented as a means to deal with site level activities. Managers must be aware that treating groundwater issues at a site level will not address potential larger scale, long-term and cumulative impacts from many site level activities that proceed within a watershed.

Groundwater plays a significant and key role in fish habitat at various scales within watersheds and lake basins. At the subwatershed and watershed scale, it provides baseflow to streams and ensures a minimum volume of water for critical living space. At the tributary and reach level it provides a moderating influence to temperature regime in the stream: cooling the stream in the summer; warming the stream in winter. At a site level, groundwater intrusions can be very important for the reproductive success of some species of fish (e.g. brook trout) in streams and lakes and can create thermal refugia from sudden and persistent temperature extremes in both summer and winter.

Although volumetrically, groundwater discharges are extremely important in the regulation of baseflow in small tributaries and headwater tributaries of watersheds, it is also extremely important in larger stream segments from a distributional perspective (i.e. thermal refugia). It is therefore extremely important to have an understanding of the groundwater and surface water interactions at various scales within a watershed and lake base in order to place into context how groundwater moves through the system in regional and shallow systems and the characteristics of various depth water tables in time and space.

An understanding of groundwater flow and its inherent complexity, given various surficial and bedrock geologies, is critically important as a first step in understanding how potential changes in the use of land can alter pathways and volumes of movement of groundwater from infiltration areas through a system and into streams and lakes.

Various land use activities will have variable impacts on groundwater patterns and fish habitat. These impacts will depend upon the activity, the site, the physiography of the watershed, location within the watershed, whether it is a regional or shallow groundwater system and the nature and location of aquatic environments near the proposed site of activity. It is extremely important that an understanding of the mechanisms of change to groundwater movement (infiltration, flow and discharge) be understood for different types

of land use activities so that relevant information can be collected in order to determine potential impacts on aquatic environments in general and fish habitat specifically. This information is important for the development of strategies to protect groundwater characteristics and to provide a starting point for determination of the data requirements necessary to scope potential impacts.

The decision framework and flow chart provided in this report can be used by both physical and biological scientist and managers. It is designed to help determine potential problems, determine potential impacts on fish habitat (if there may be any) and determine relevant questions to ask. From this approach appropriate methods for answering the questions can be determined by trained hydrogeologists. This information can be used to determine if groundwater flow patterns and fish habitat in the vicinity of the site will be affected by the activity. Decisions on the nature of the activity, and possible controls can then be made. Monitoring of the effectiveness of the controls is essential in order to determine if the controls are effective or must be modifies. Monitoring information can also improve the reliability of the initial analysis and provide additional information for future decisions based on similar situations.

8.0 REFERENCES

- Benson, N.G. 1953. The importance of groundwater to trout populations in the Pigeon River, Michigan. *Trans. 18th N. Amer. Wildl. Conf.* pp. 269-281.
- Bilby, E.A. 1984. Characteristics and frequency of cool-water areas in a western Washington stream. *Freshwat. Ecol.* 2: 593-602.
- Blackport, R. 1995. Hydrological impact figures for changing land uses. Terraqua Investigations Ltd., Waterloo, Ontario.
- Bowlby, J.N. and J. Roff. 1986. Trout biomass and habitat relationships in southern Ontario streams. *Trans. Amer. Fish. Soc.* 115: 503-514.
- Chow, V.T. 1964. Runoff. *In* Chow, V.T. (ed.). *Handbook of applied hydrology*. pp. 14-1 - 14-54. McGraw-Hill Book Company, New York.
- Cunjak, R.A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). *Can. J. Fish. Aquat. Sci.* 43: 1970-1981.
- Freeze, A.R. and J.A. Cherry. 1979. *Groundwater*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.
- Hanson E.A. 1975. Some effects of groundwater on brown trout redds. *Trans. Amer. Fish. Soc.* 104: 100-110.
- HSP Inc. 1992. Long term effectiveness and design considerations for buffer strips on agricultural lands: background paper. London, ON. 57p.
- Hynes, H.B.N. 1983. Groundwater and stream ecology. *Hydrobiologia* 100: 93-99.
- Hynes, H.B.N. 1970. *The ecology of running waters*. University of Toronto Press, Toronto, Ontario.
- Imhof, J.G., R.J. Planck, F. Johnson and L. Halyk. 1991. Watershed urbanization and stream habitats for fish. *In* R.E. McCabe (ed.). *Proceedings of the 56th North American Wildlife and Natural Resources Conference*. Edmonton: Wildlife Management Institute. pp. 269-285.
- Klein, R.D. 1979. Urbanization and stream quality impairment. *Wat. Resour. Bull.* 15: 948-963.

- Latta, W.C. 1965. Relationship of young-of-the-year trout to mature trout and groundwater. *Trans. Amer. Fish. Soc.* 94: 32-39.
- Meisner, J.D., J.S. Rosenfield and H.A. Regier. 1998. The role of groundwater in the impact of climate warming on stream salmonines. *Fisheries* 13: 2-8.
- Ontario Ministry of Agriculture and Food, Ontario Ministry of Environment, Ontario Ministry of Housing. 1976. Agricultural code of practice. 43p.
- Robertson, W.D., J.A. Cherry, and E.A. Sudicky. 1991. Ground-water contamination from two small septic systems on sand aquifers. *Ground Water* 29(1) 82-92.
- Sawney, B.L., and J.L. Starr. 1977. Movement of phosphorous from a septic system drainfield. *Jour. Water Poll. Control Fed.* 49(11) 2238-2242.
- Sawhney, B.L., and D.E. Hill. 1975. Phosphate sorption characteristics of soils treated with domestic waste water. *J. Environ. Qual.* 4(3) 342-346.
- Sowden, T.K. and G. Power. 1985. Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. *Trans. Amer. Fish. Soc.* 114: 804-812.
- Steedman, R.J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. *Can. J. Fish. Aquat. Sci.* 45: 492-501.
- Steedman, R.J. 1987. Comparative analysis of stream degradation and rehabilitation in the Toronto area. PhD thesis, University of Toronto. pp. 1-172.
- Whelan, B.R., and N.J. Barrow. 1984. The movement of septic tank effluent through sandy soils near Perth. II Movement of phosphorus. *Aust. J. Soil Res.* 22: 293-302.
- Wickett, W.P. 1954. The oxygen supply to salmon eggs in spawning beds. *J. Fish. Res. Bd. Can.* 11: 933-953.
- Witzel, L.D. and H.R. MacCrimmon. 1983. Redd-site selection by brook trout and brown trout in southwestern Ontario streams, *Trans. Amer. Fish. Soc.* 112: 760-771.

TABLES

TABLE 1. Potential Fisheries Related Groundwater Impacts From Land Use Activities

LAND USE	POTENTIAL GROUNDWATER IMPACT (H, M, L)			
	Volumetric Baseflow	Direct Discharge	Water Quality	Recharge
Aggregate - dewatering - dragline	H L	H M	M L	H L
Rural development - individual wells - communal wells - septic systems - storm water	M H L L	L H L M	L M H M	L H M M
Urban Hamlet - private wells - municipal wells - septic system - storm water	M H L M	L H L M	L M H M	L H M M
Industrial - dry facilities - wet facilities	L H	L H	M M	L H
Agriculture - row crop - hay/pasture	L L	L L	M L	L L
Other - gas station - roads	L L	L L	H H	L L

TABLE 2. Potential Function of the Hydrogeologic Setting

SETTING	POTENTIAL GROUNDWATER FUNCTION (H, M, L)			
	Volumetric Baseflow	Direct Discharge	Water Quality	Recharge
A) AQUIFER (permeable deposit)				
1) Unconfined				
a) recharge area - local	H	H	H	H
- regional	H	L	L	H
b) discharge area - local	H	H	H	L
- regional	H	H	H	L
2) Semi-confined				
a) recharge area - local	M	M	M	M
- regional	M	L	L	L
b) discharge area - local	M	H	M	L
- regional	M	M	M	L
3) Confined	L	L	L	L
B) NON-AQUIFER				
1) Moderate permeability				
a) uniform geologic material	M	L	L	M
b) non-uniform geologic material (e.g. layered, pockets)	M	M	M	M
2) Low permeability (e.g. clay till)	L	L	L	L

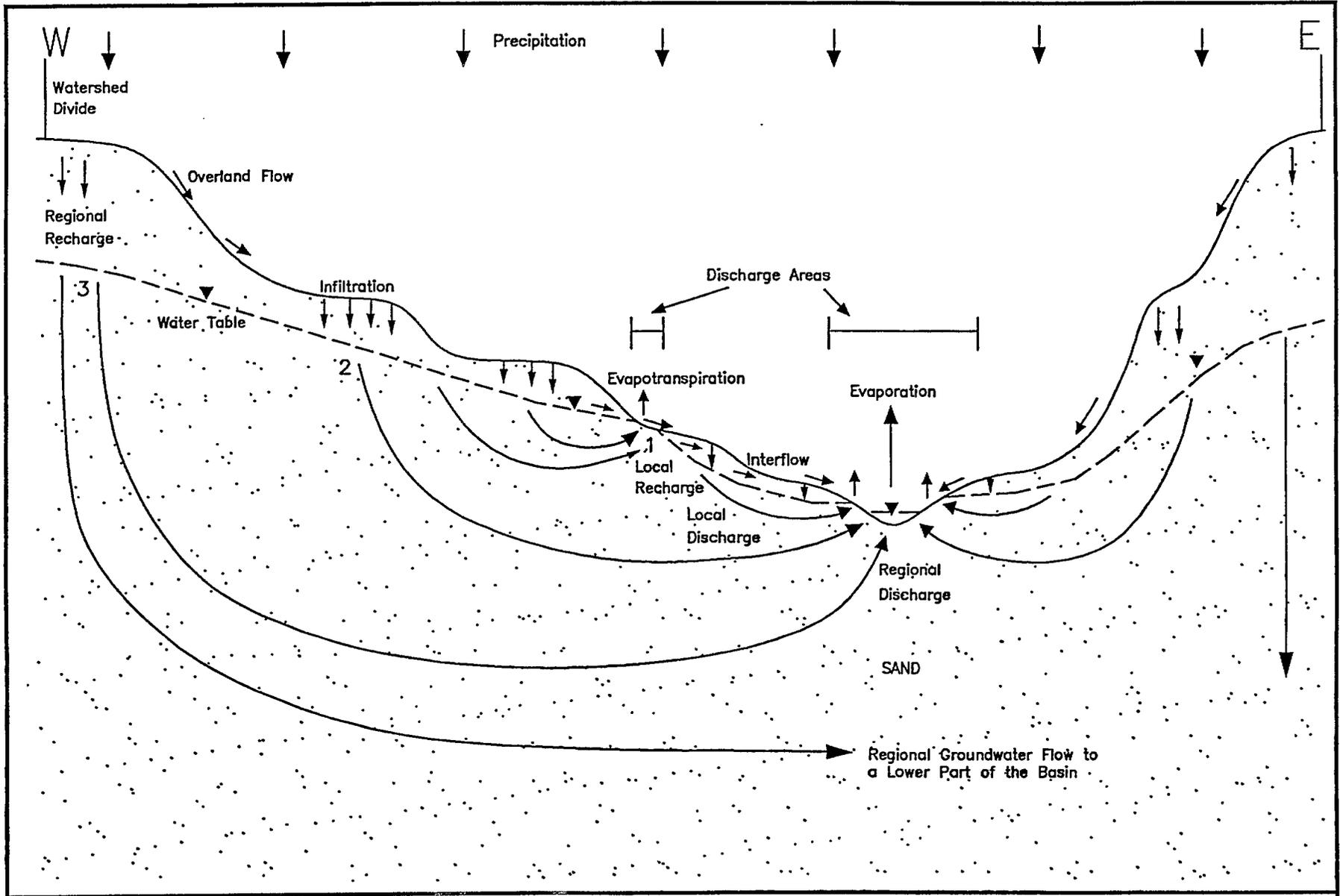


FIGURE 1 GROUNDWATER FLOW IN A SIMPLE GEOLOGICAL SETTING

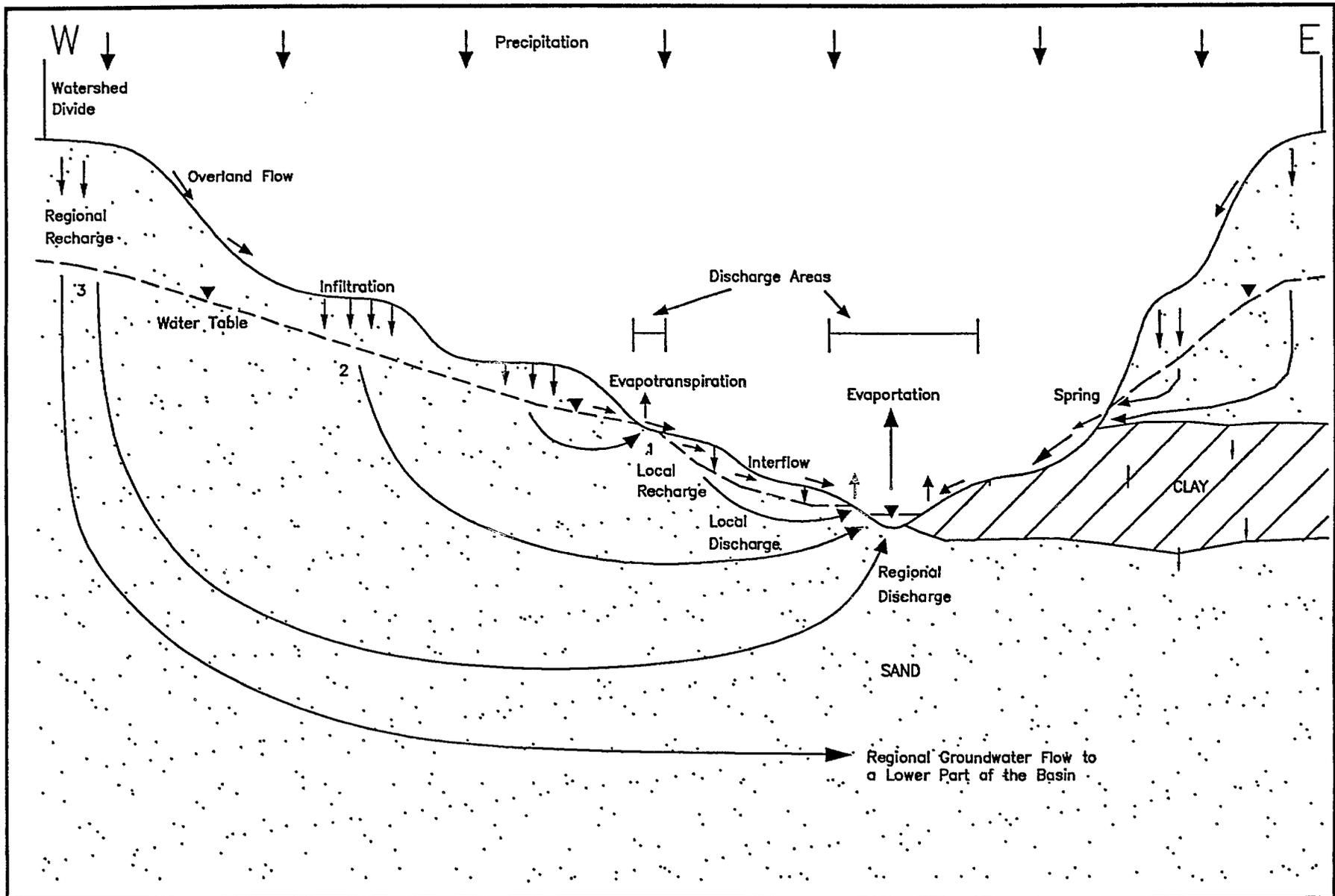


FIGURE 2 INFLUENCE OF CLAY LAYER ON GROUNDWATER FLOW

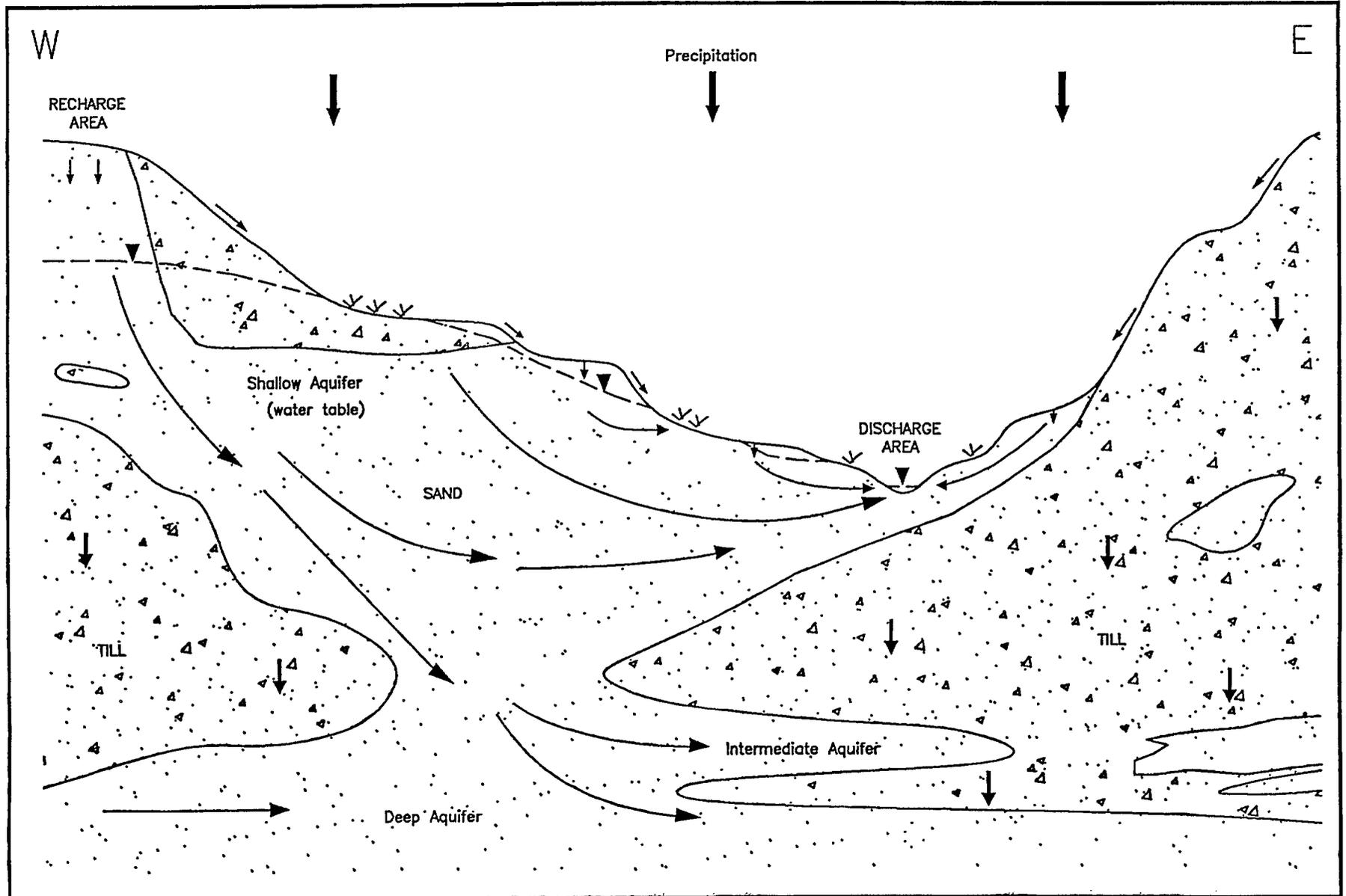


FIGURE 3 GROUNDWATER FLOW IN A COMPLEX GEOLOGIC SETTING

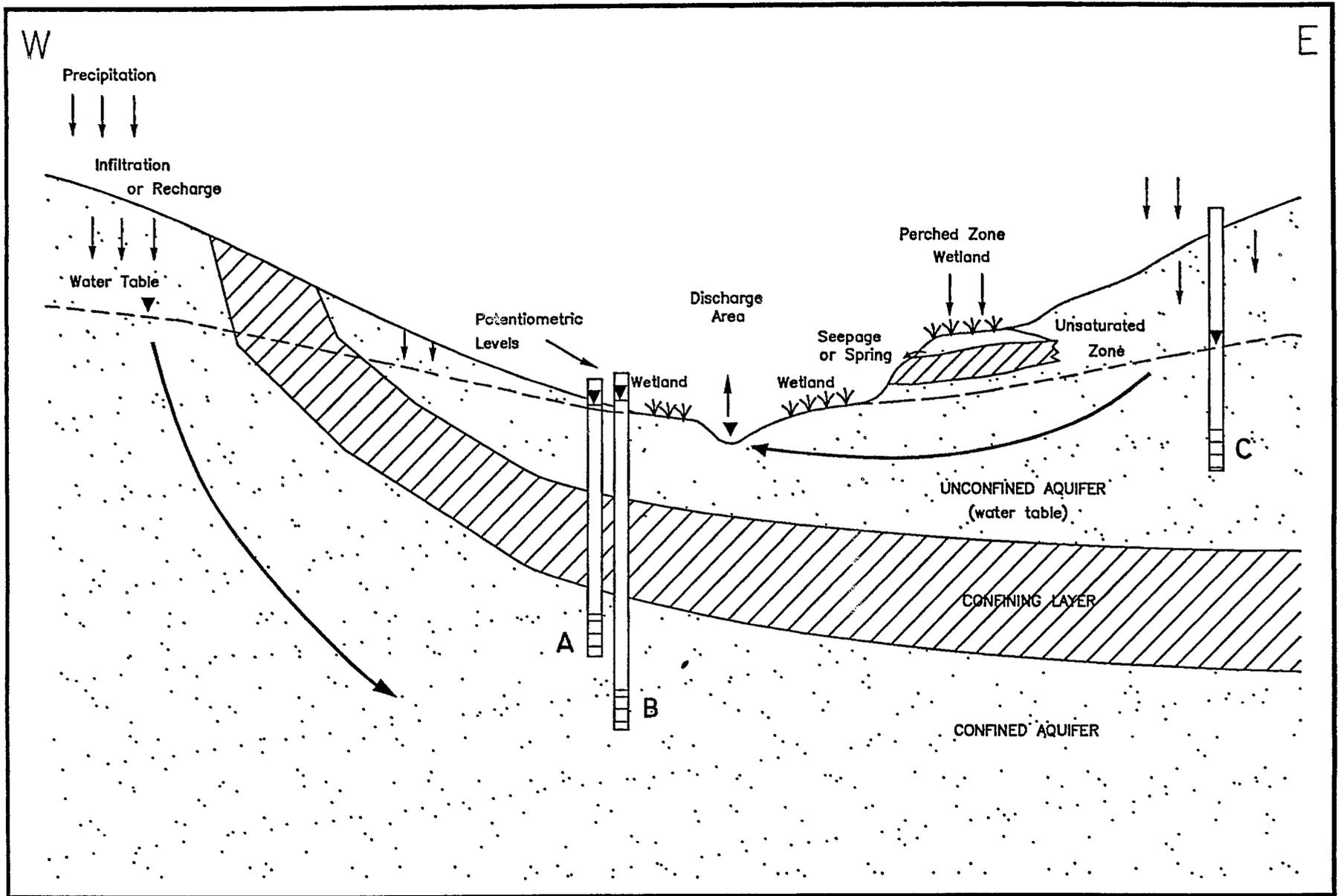


FIGURE 4 GENERALIZED GROUNDWATER FLOW

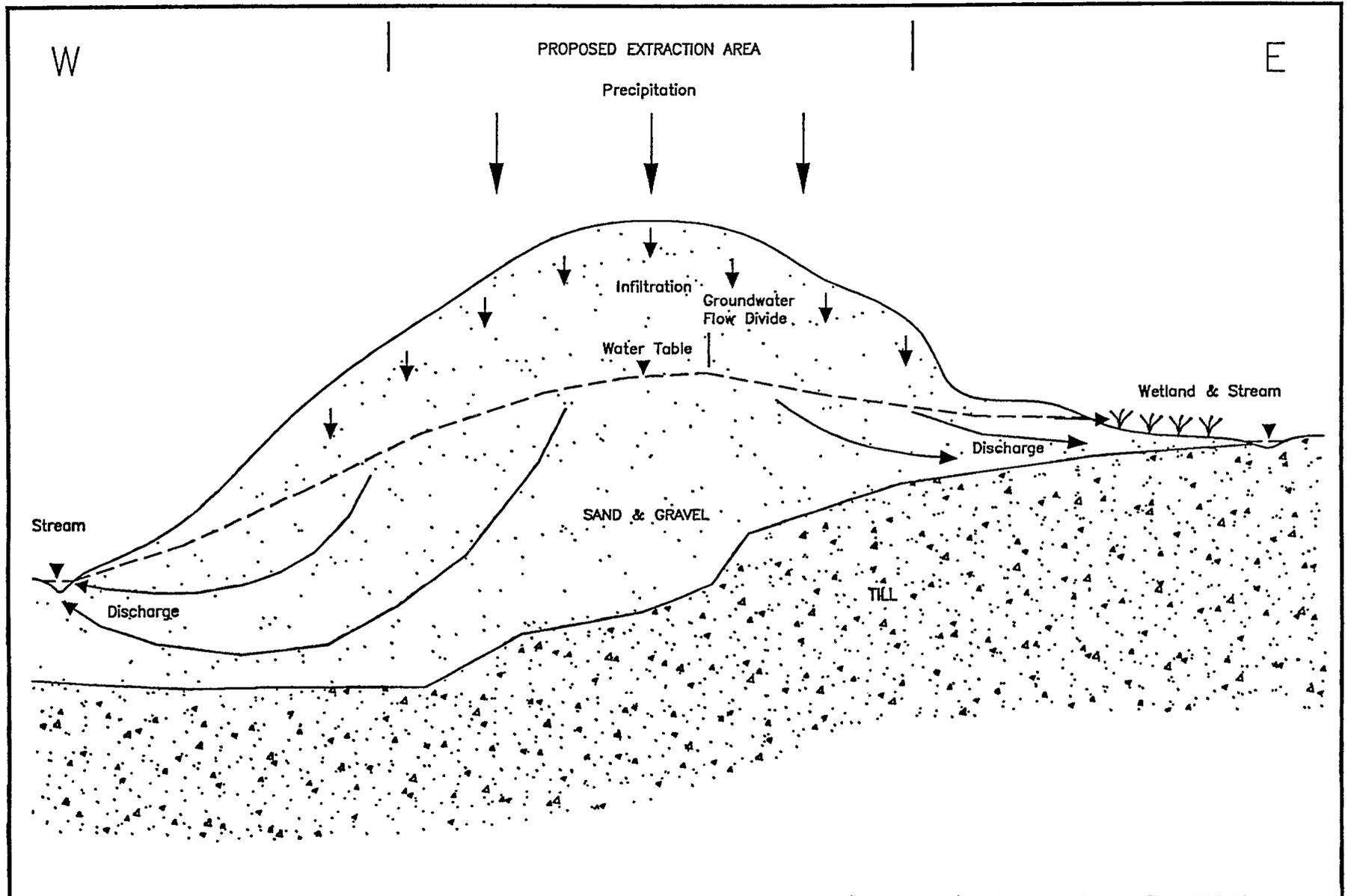


FIGURE 5 AGGREGATE EXTRACTION - SAND AND GRAVEL - EXAMPLE OF EXISTING CONDITIONS

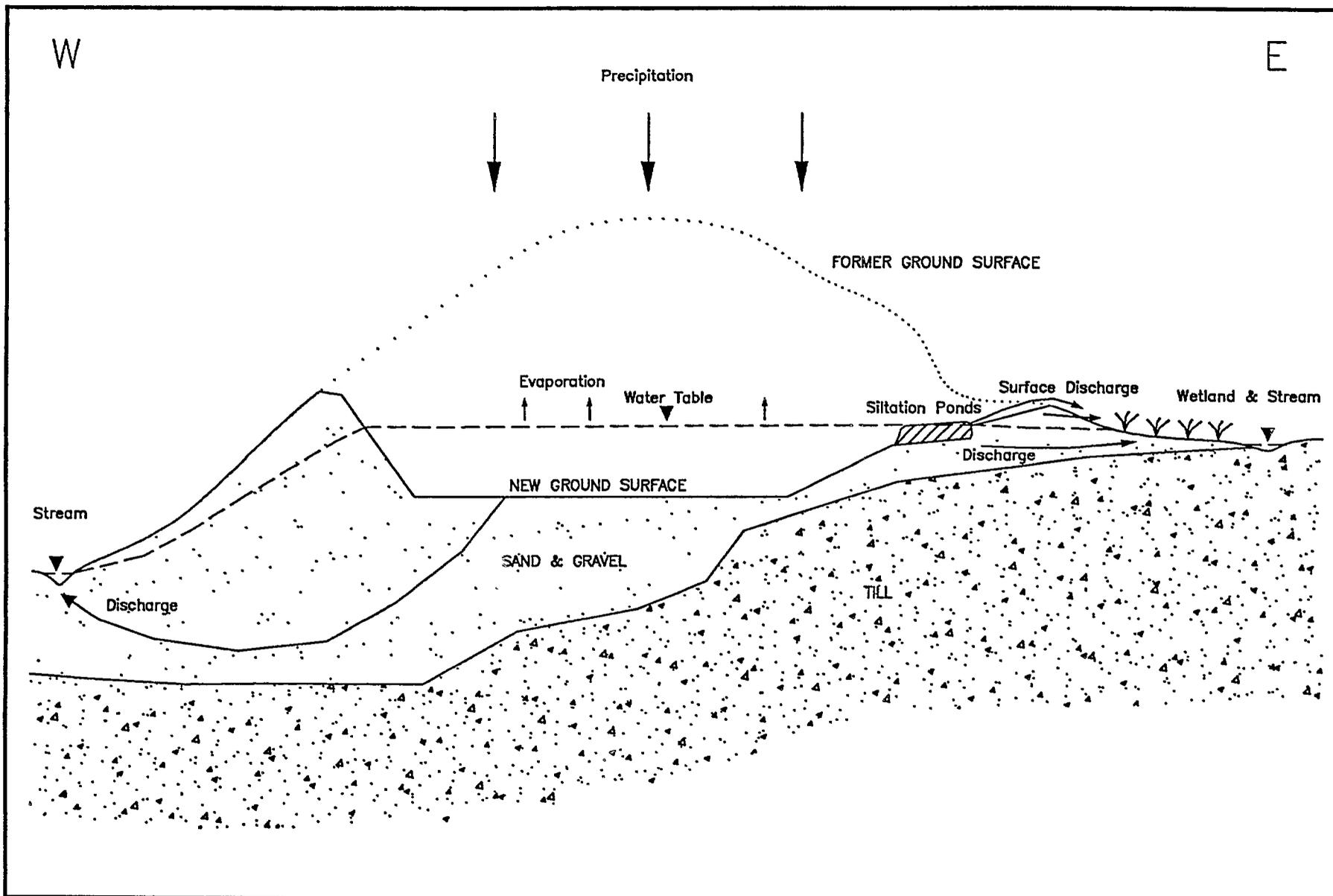


FIGURE 6 AGGREGATE EXTRACTION - SAND AND GRAVEL - EXAMPLE OF POTENTIAL IMPACT

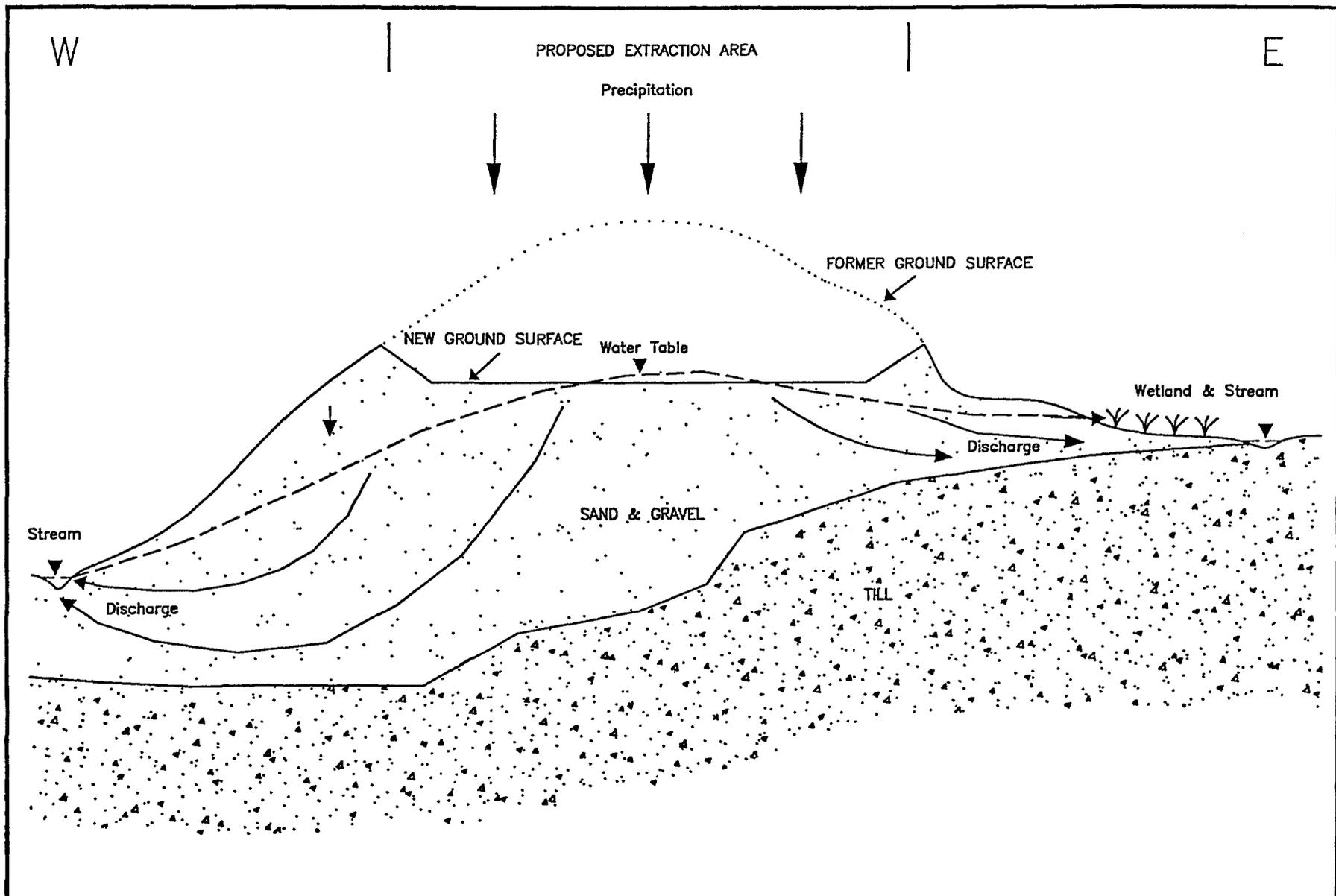


FIGURE 7 AGGREGATE EXTRACTION - SAND AND GRAVEL - EXAMPLE OF MITIGATION OF POTENTIAL IMPACTS

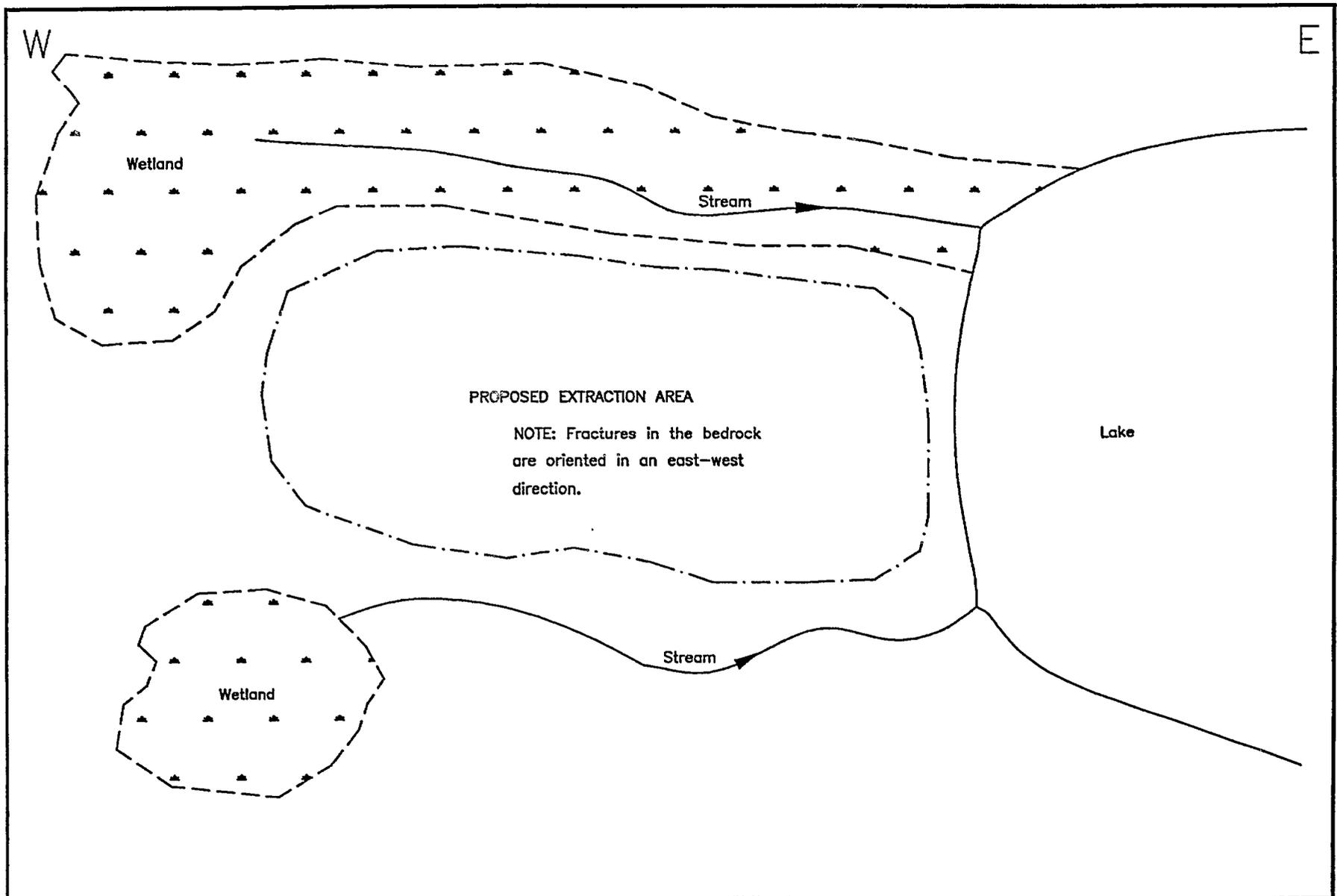


FIGURE 8 AGGREGATE EXTRACTION - BEDROCK - EXAMPLE OF PRESENT CONDITIONS IN PLAN VIEW

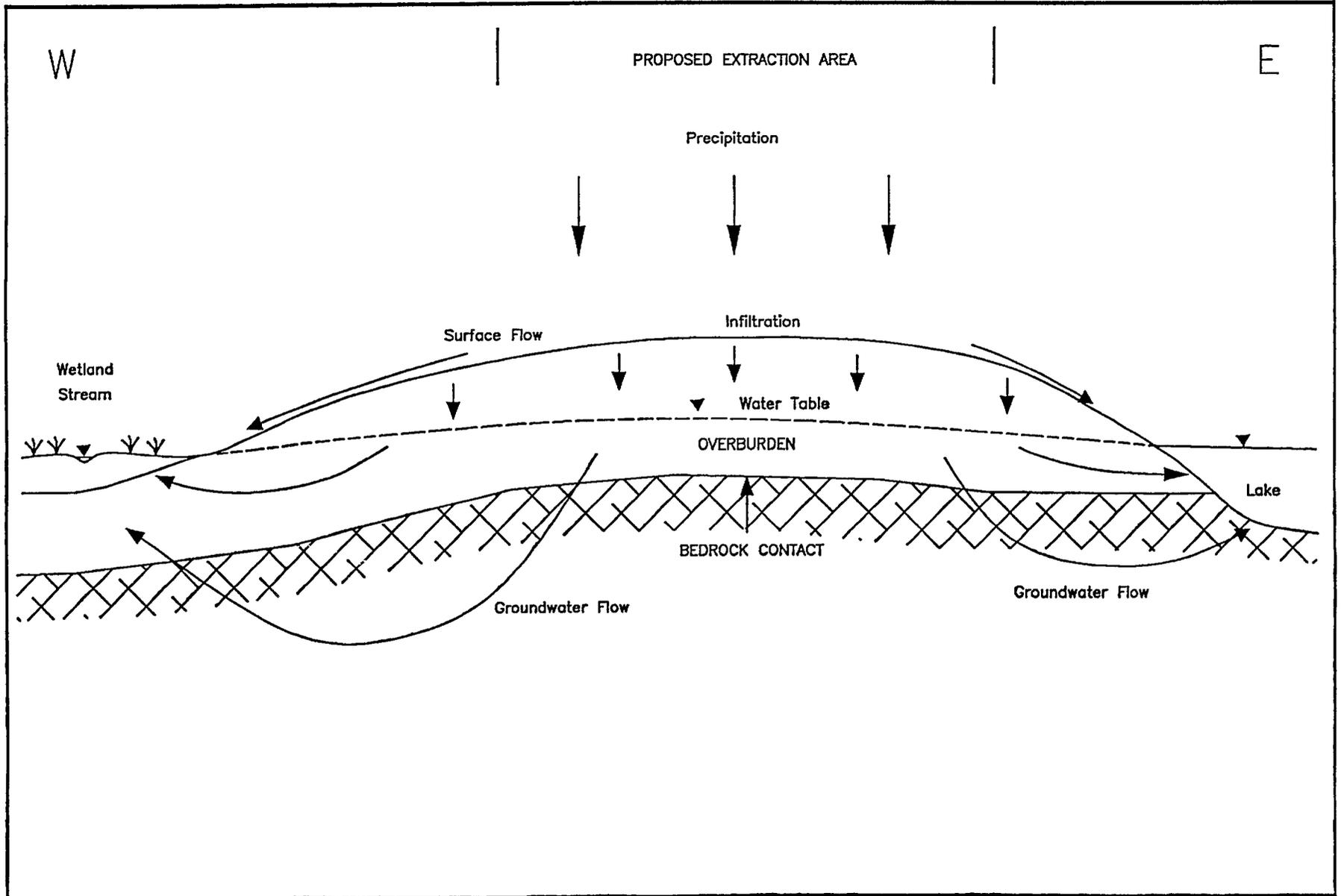


FIGURE 9 AGGREGATE EXTRACTION - BEDROCK - EXAMPLE OF PRESENT CONDITIONS IN CROSS-SECTION

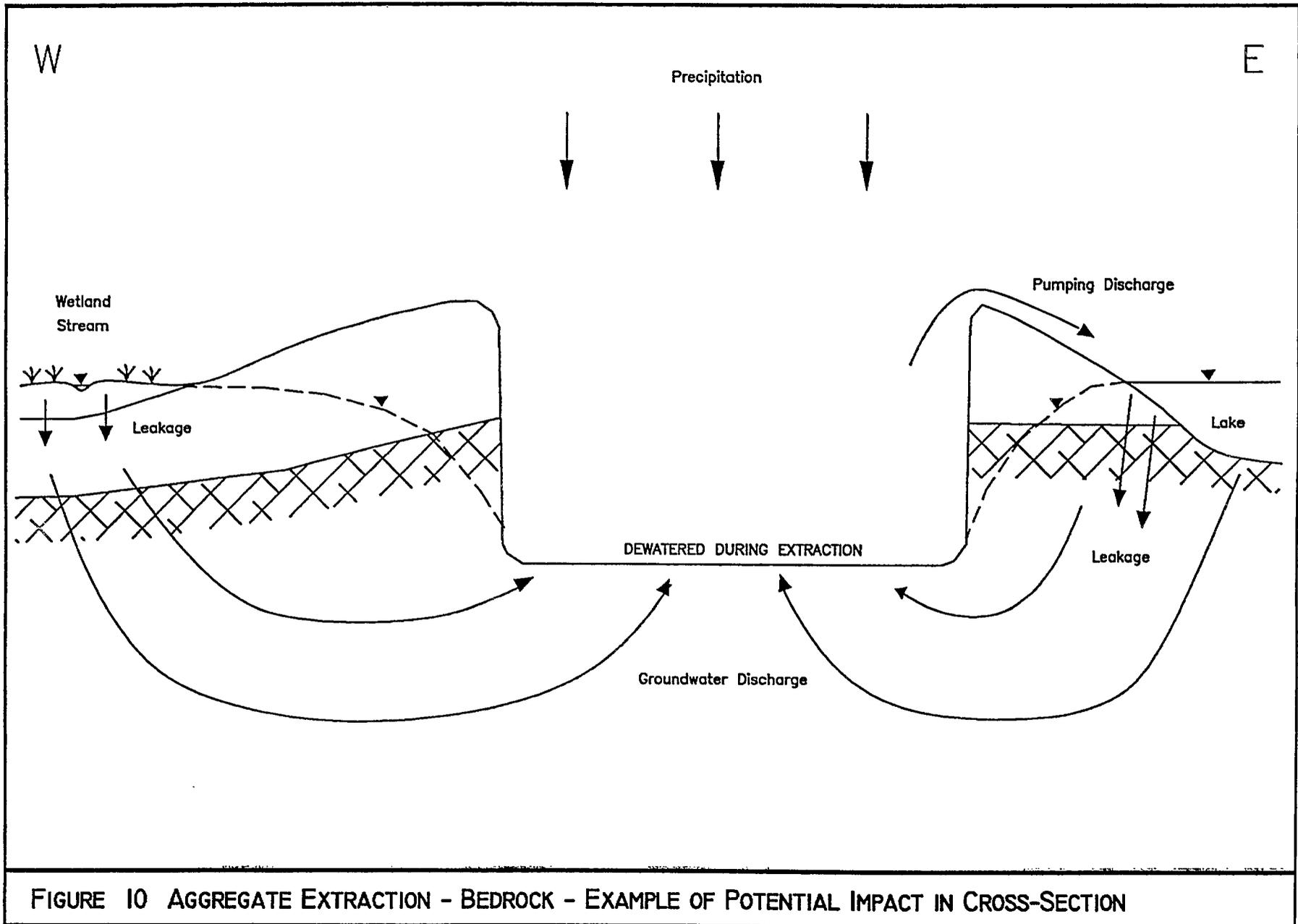


FIGURE 10 AGGREGATE EXTRACTION - BEDROCK - EXAMPLE OF POTENTIAL IMPACT IN CROSS-SECTION

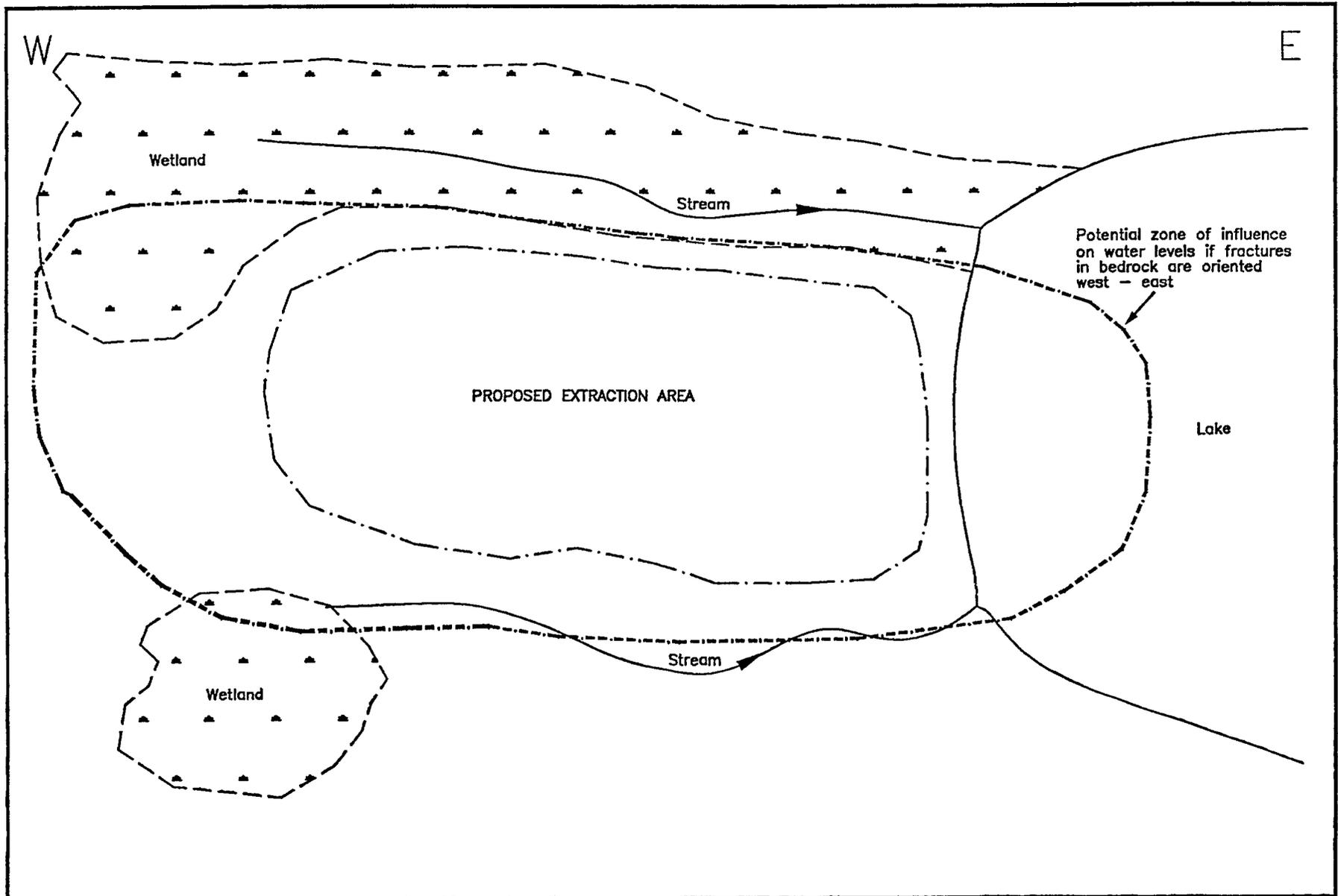


FIGURE II AGGREGATE EXTRACTION - BEDROCK - EXAMPLE OF POTENTIAL IMPACT IN PLAN VIEW

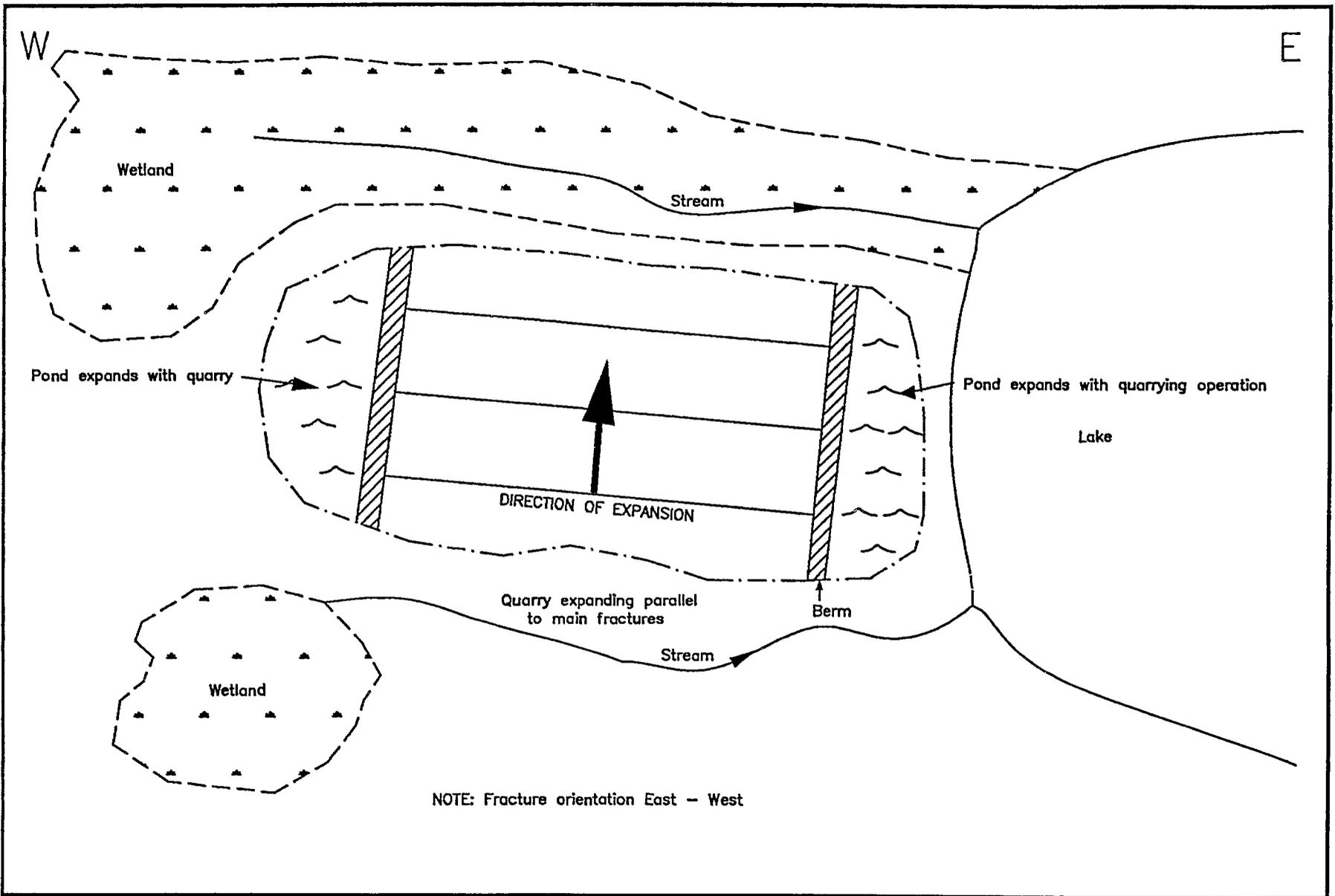


FIGURE 12 AGGREGATE EXTRACTION - BEDROCK - EXAMPLE OF MITIGATION IMPACTS IN PLAN VIEW

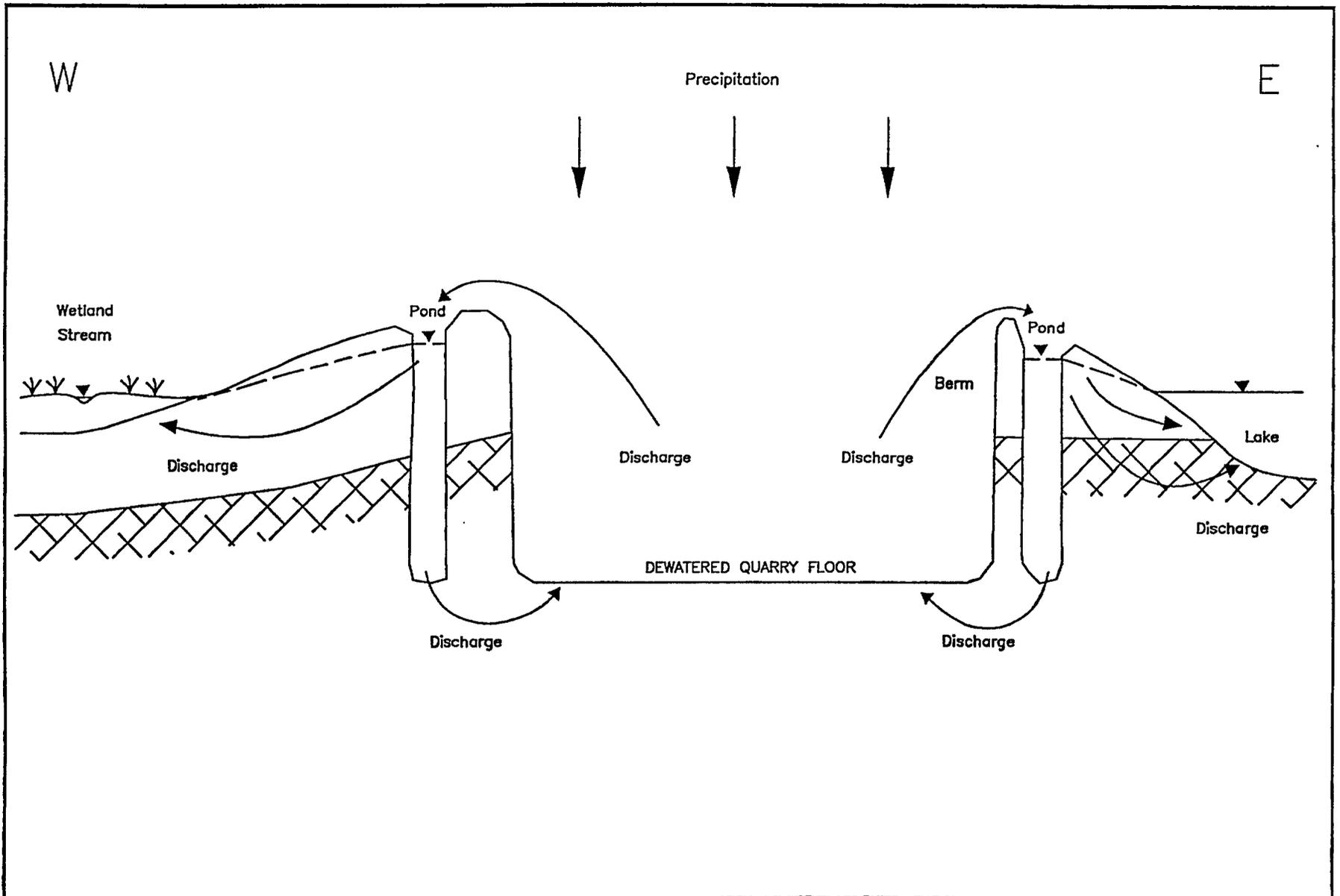


FIGURE 13 AGGREGATE EXTRACTION - BEDROCK - EXAMPLE OF MITIGATION IMPACTS IN CROSS-SECTION

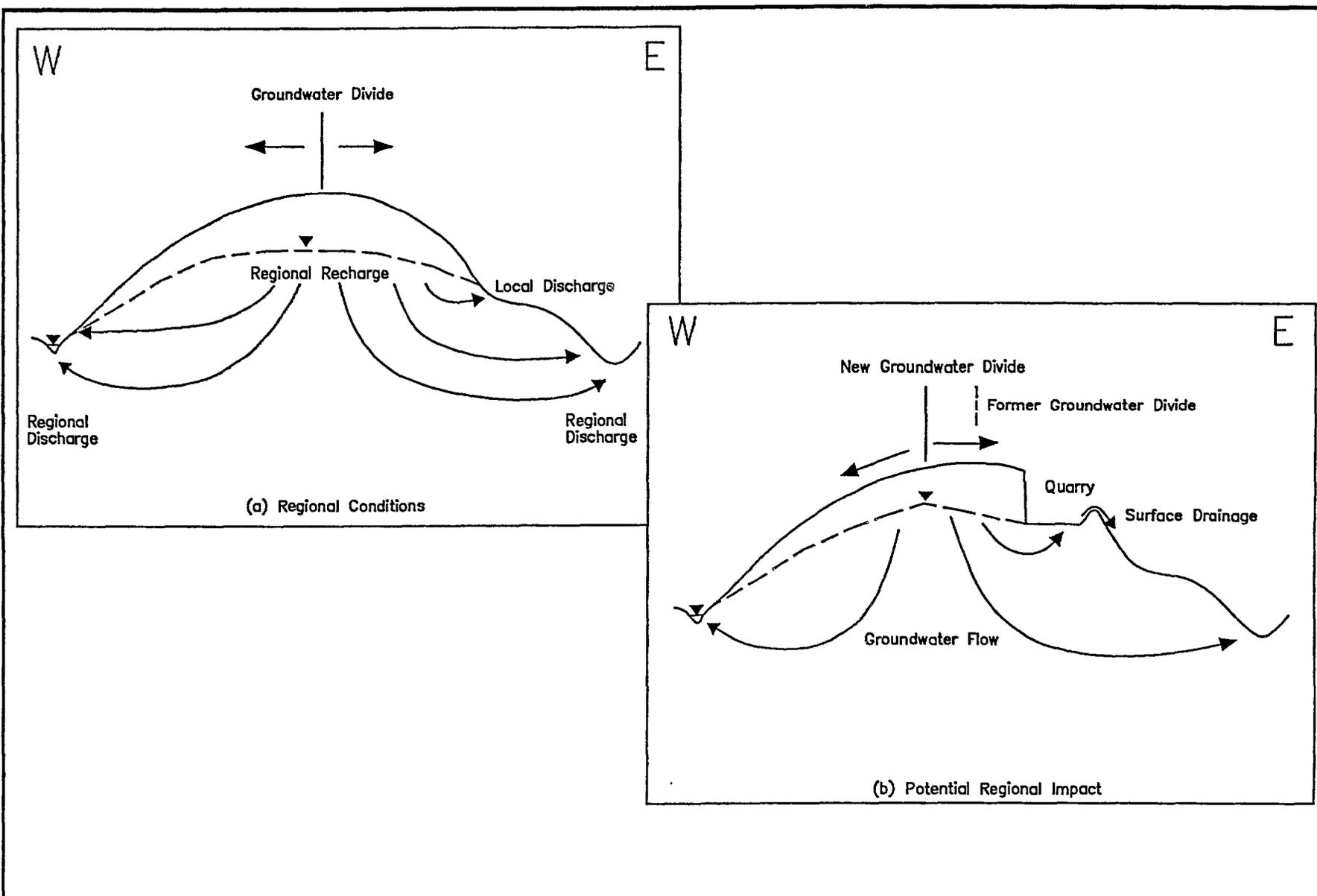


FIGURE 14 AGGREGATE EXTRACTION - REGIONAL SYSTEM

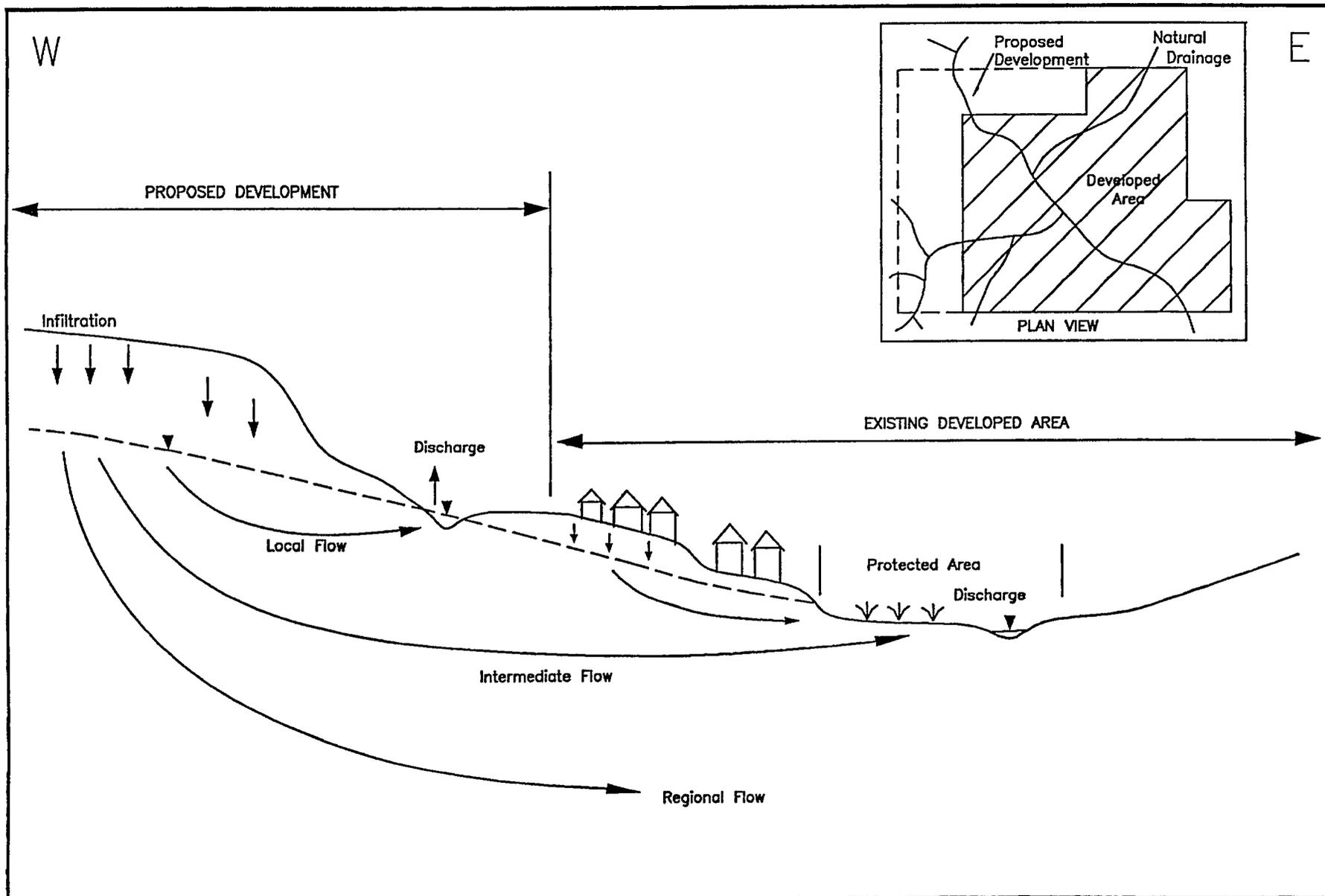


FIGURE 15 URBAN LAND USE CHANGES - EXAMPLE OF EXISTING CONDITIONS

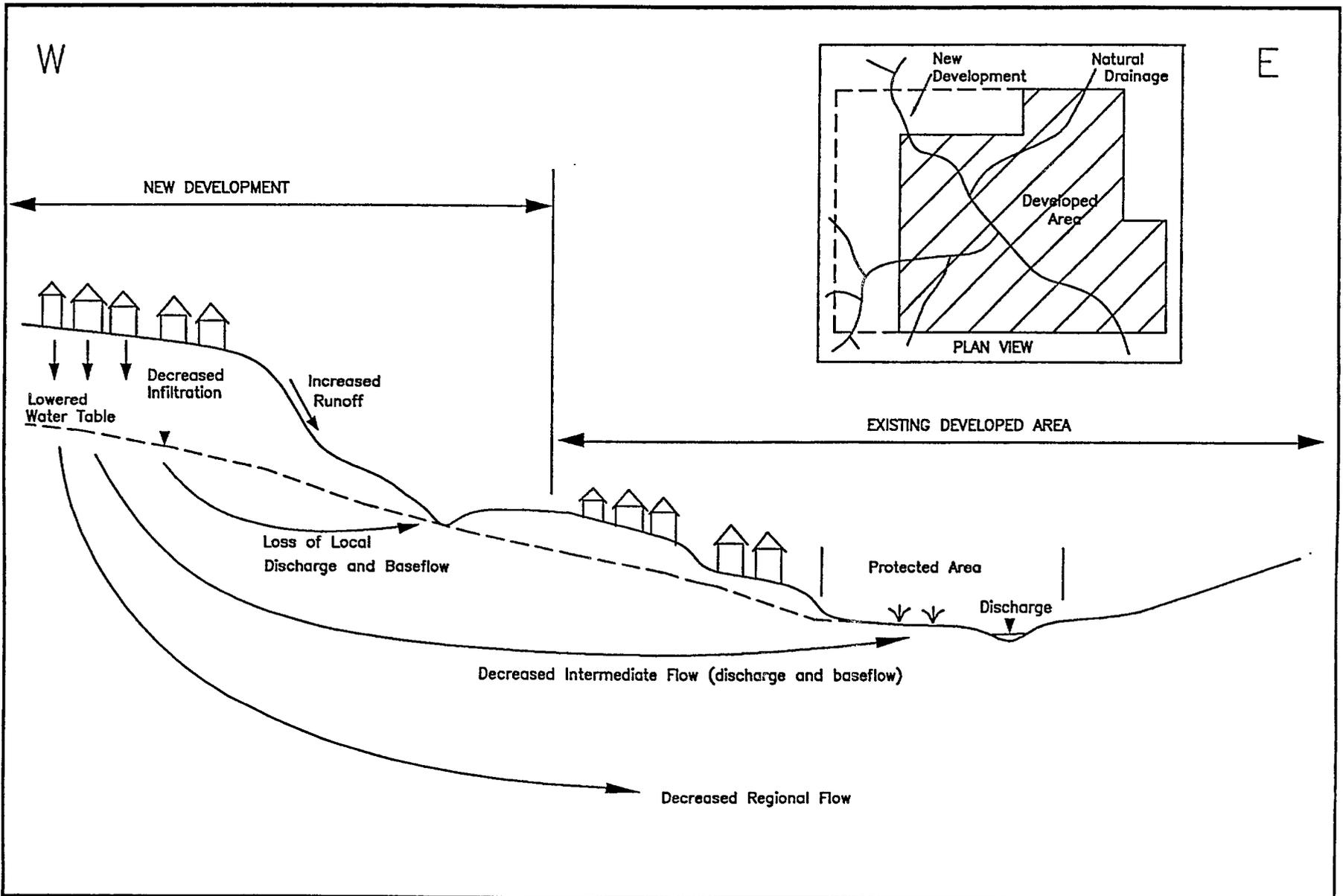


FIGURE 16 URBAN LAND USE CHANGES - EXAMPLE OF DEVELOPMENT IMPACTS

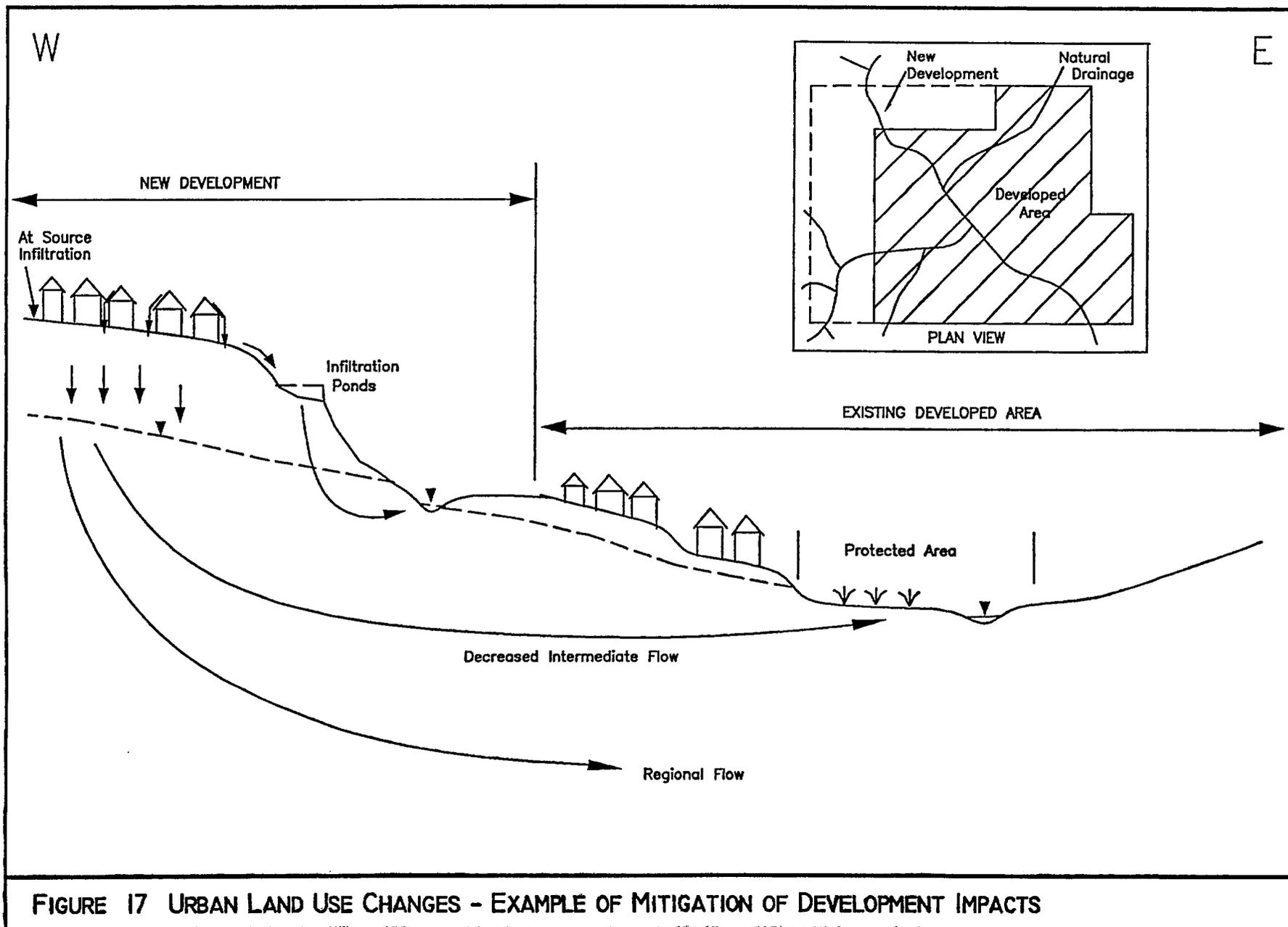
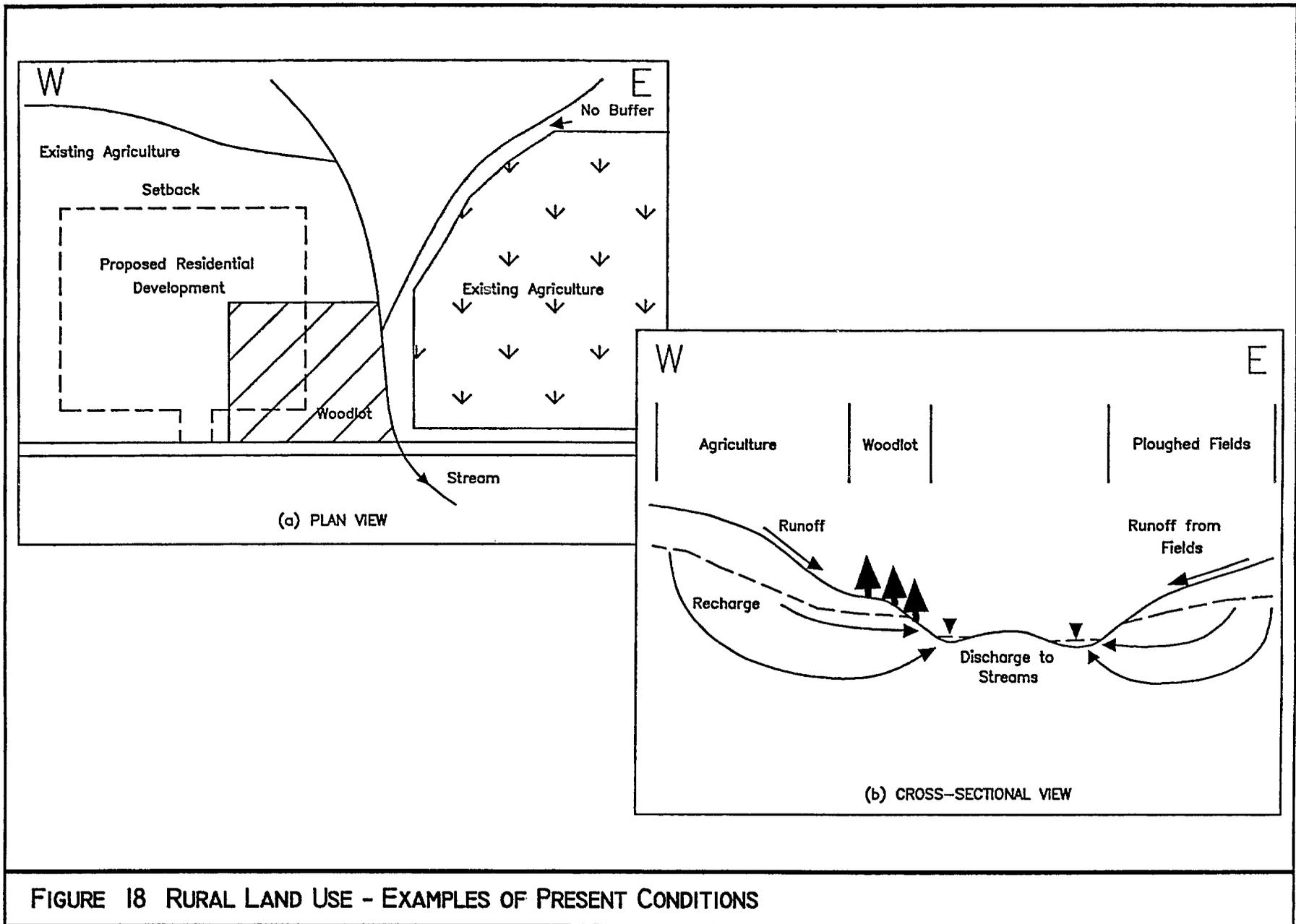


FIGURE 17 URBAN LAND USE CHANGES - EXAMPLE OF MITIGATION OF DEVELOPMENT IMPACTS



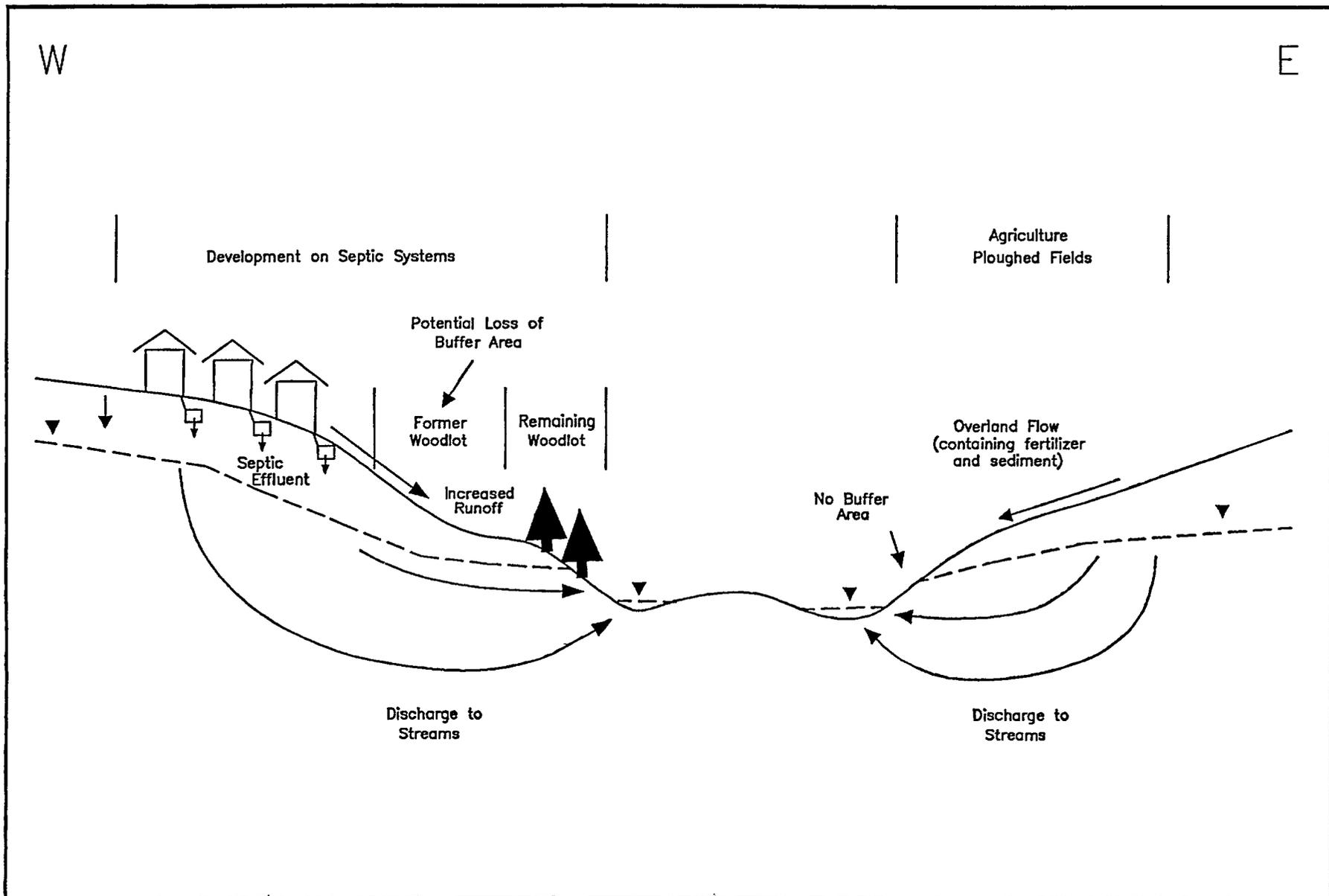


FIGURE 19 RURAL LAND USE - EXAMPLES OF POTENTIAL IMPACTS

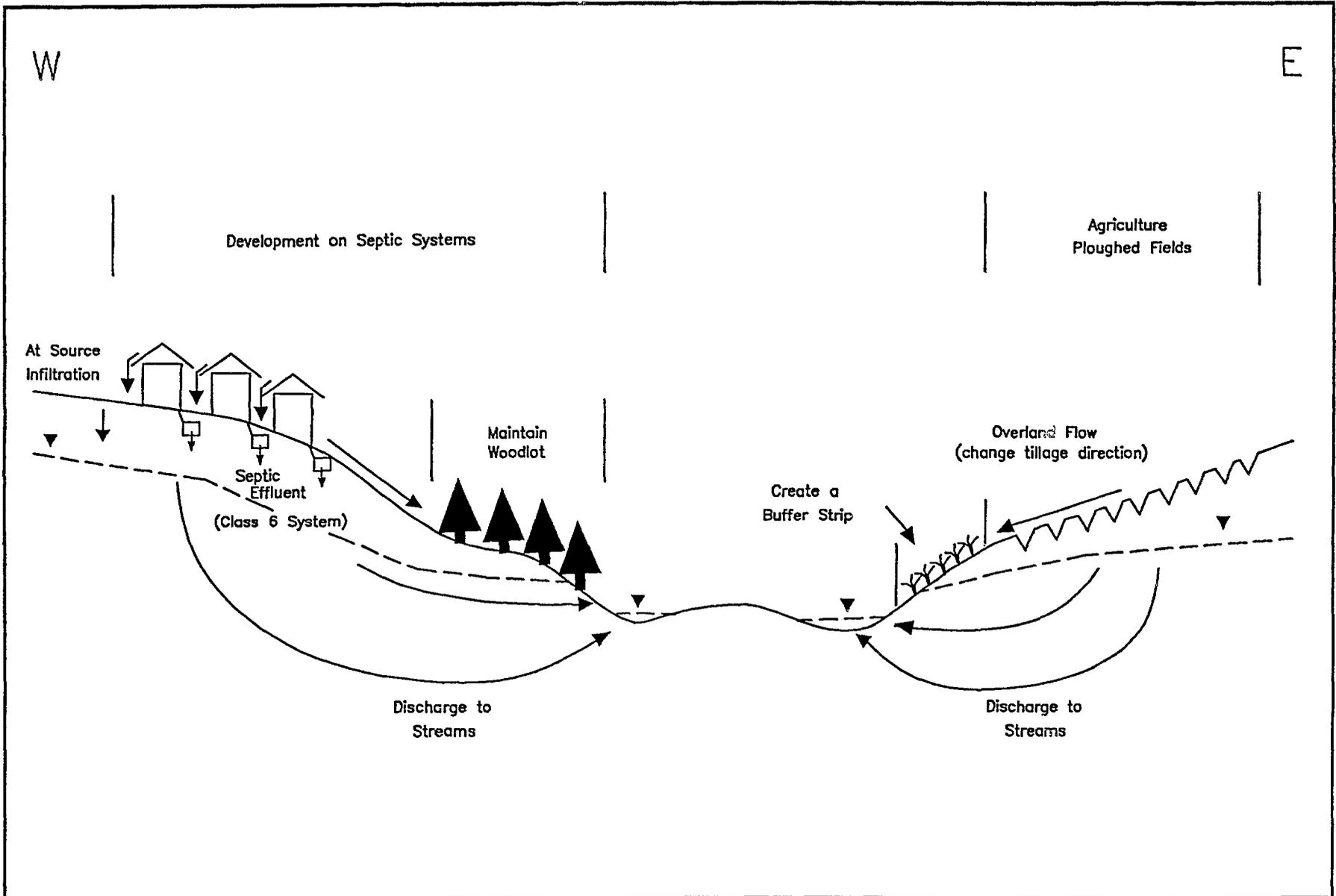


FIGURE 20 RURAL LAND USE - EXAMPLES OF POTENTIAL IMPACT CONTROLS

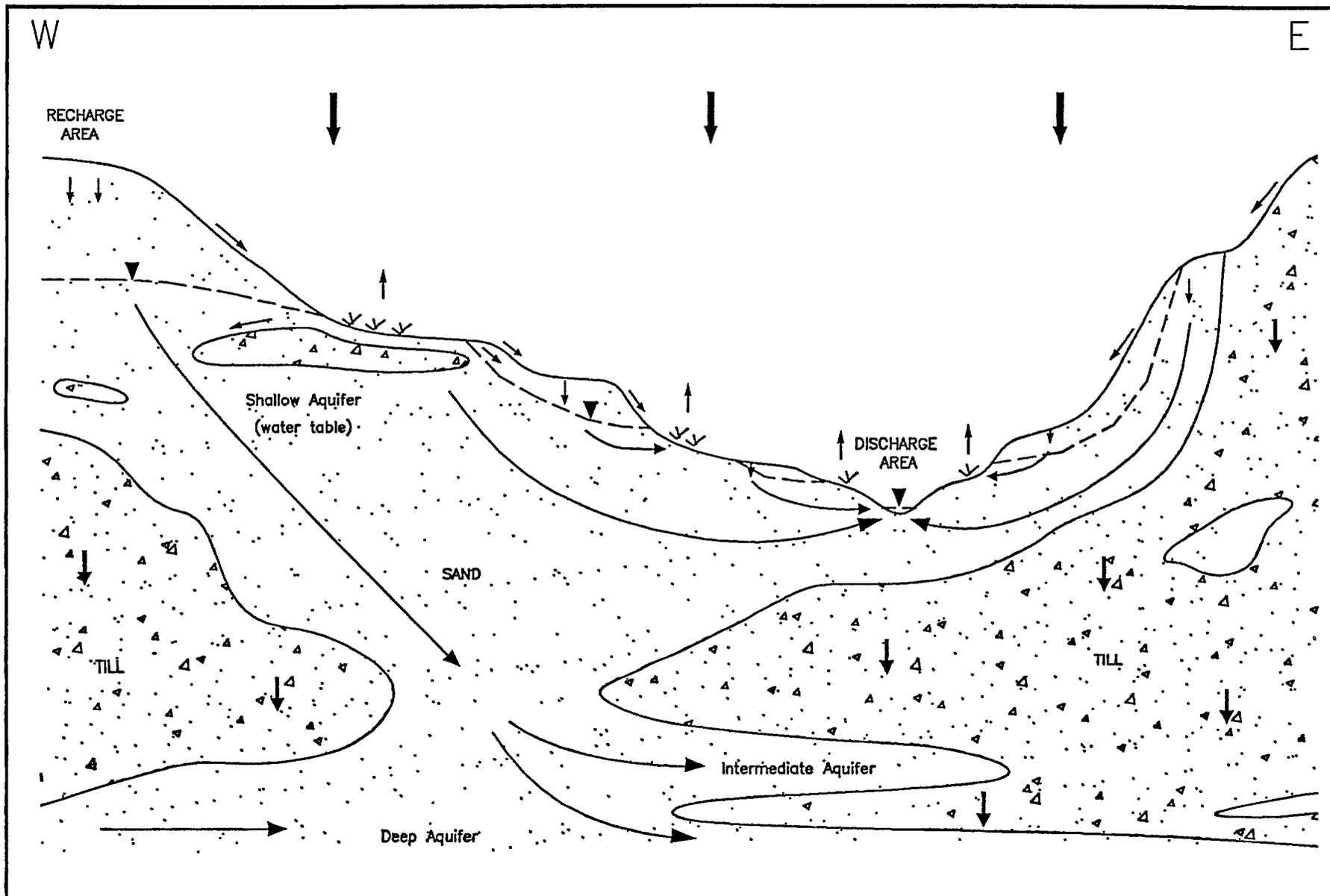


FIGURE 21 GROUNDWATER WITHDRAWAL - EXAMPLE OF PRESENT CONDITIONS

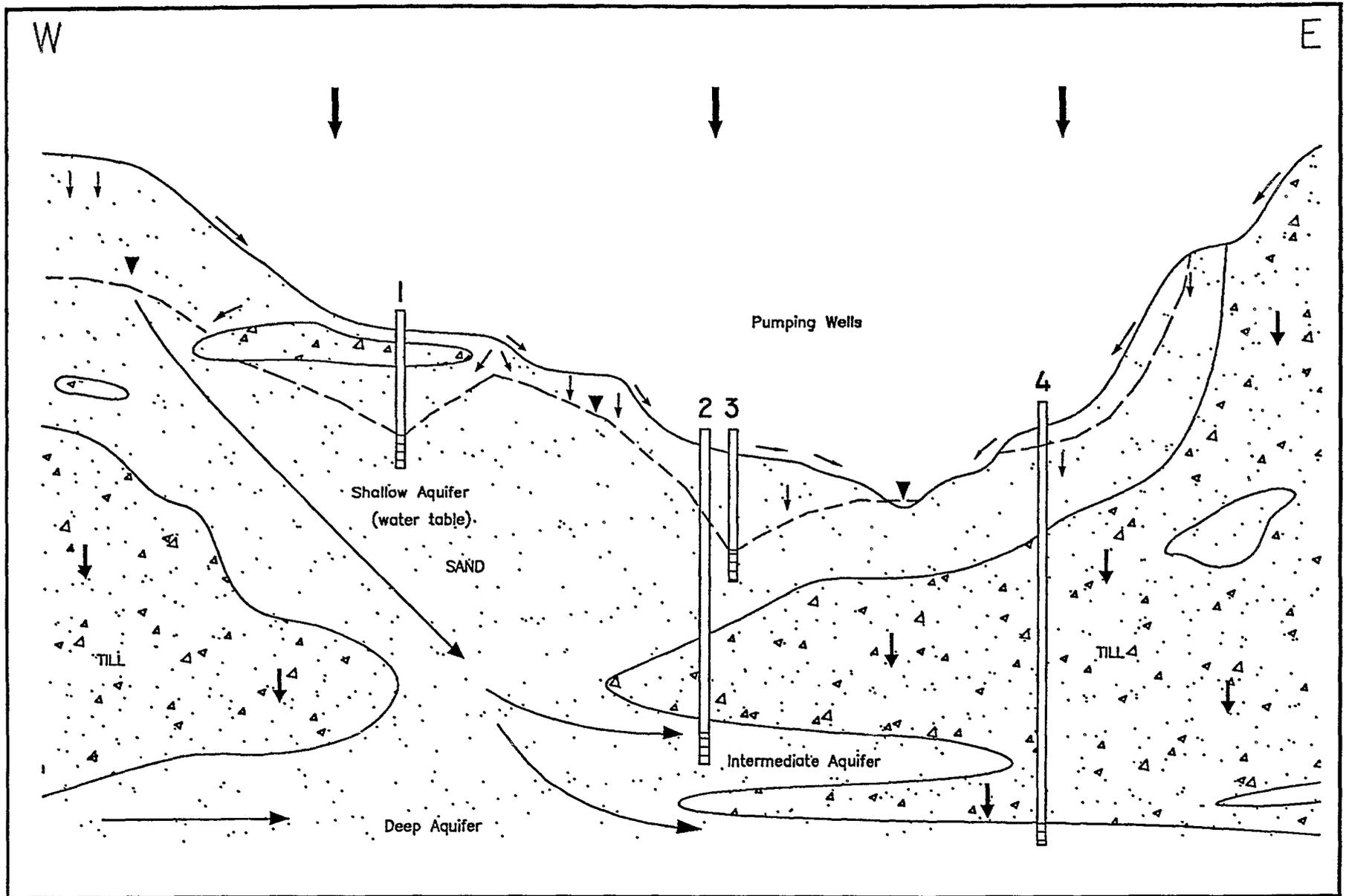


FIGURE 22 GROUNDWATER WITHDRAWAL - EXAMPLE OF POTENTIAL IMPACTS

Figure 23. General Framework

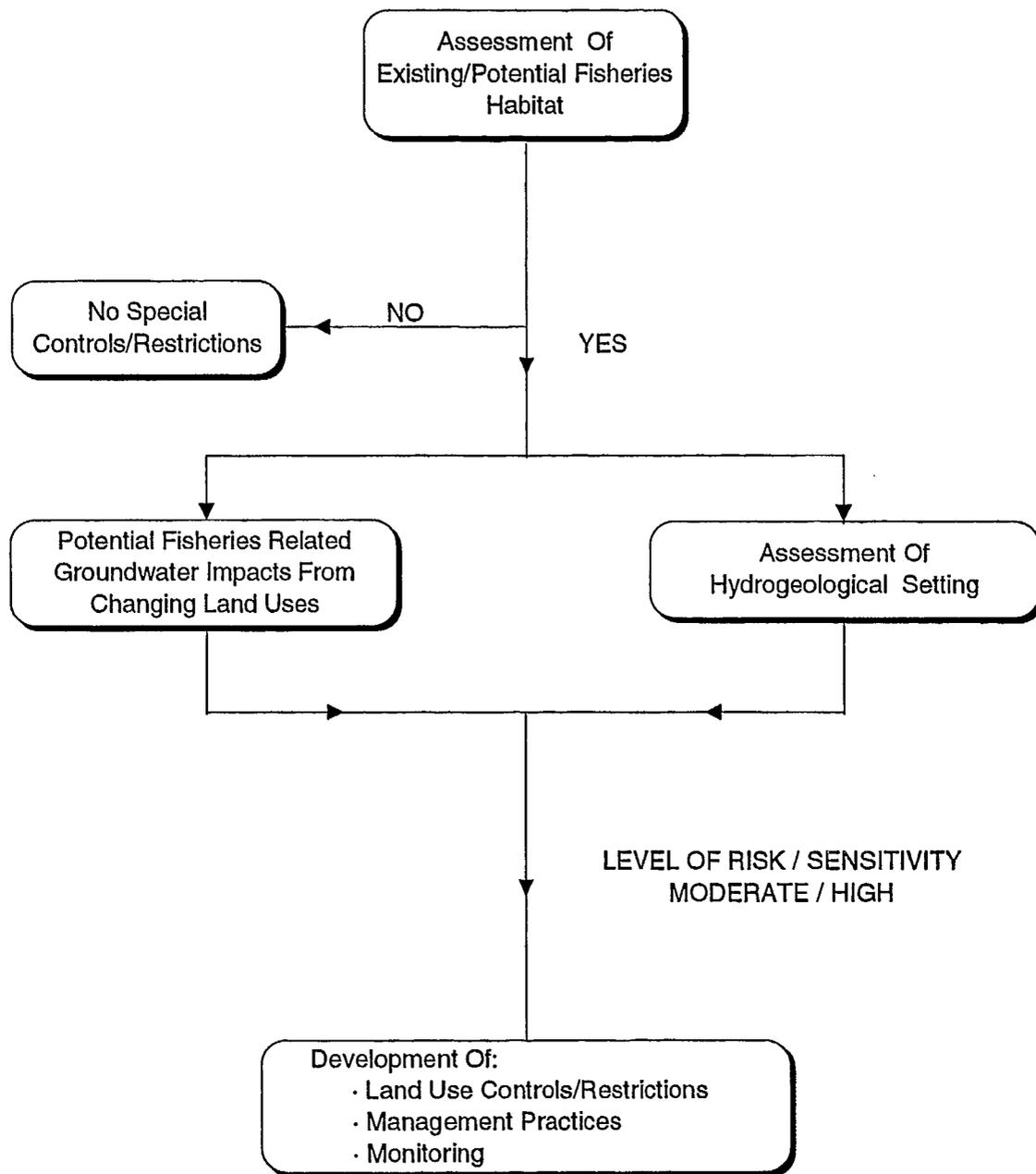
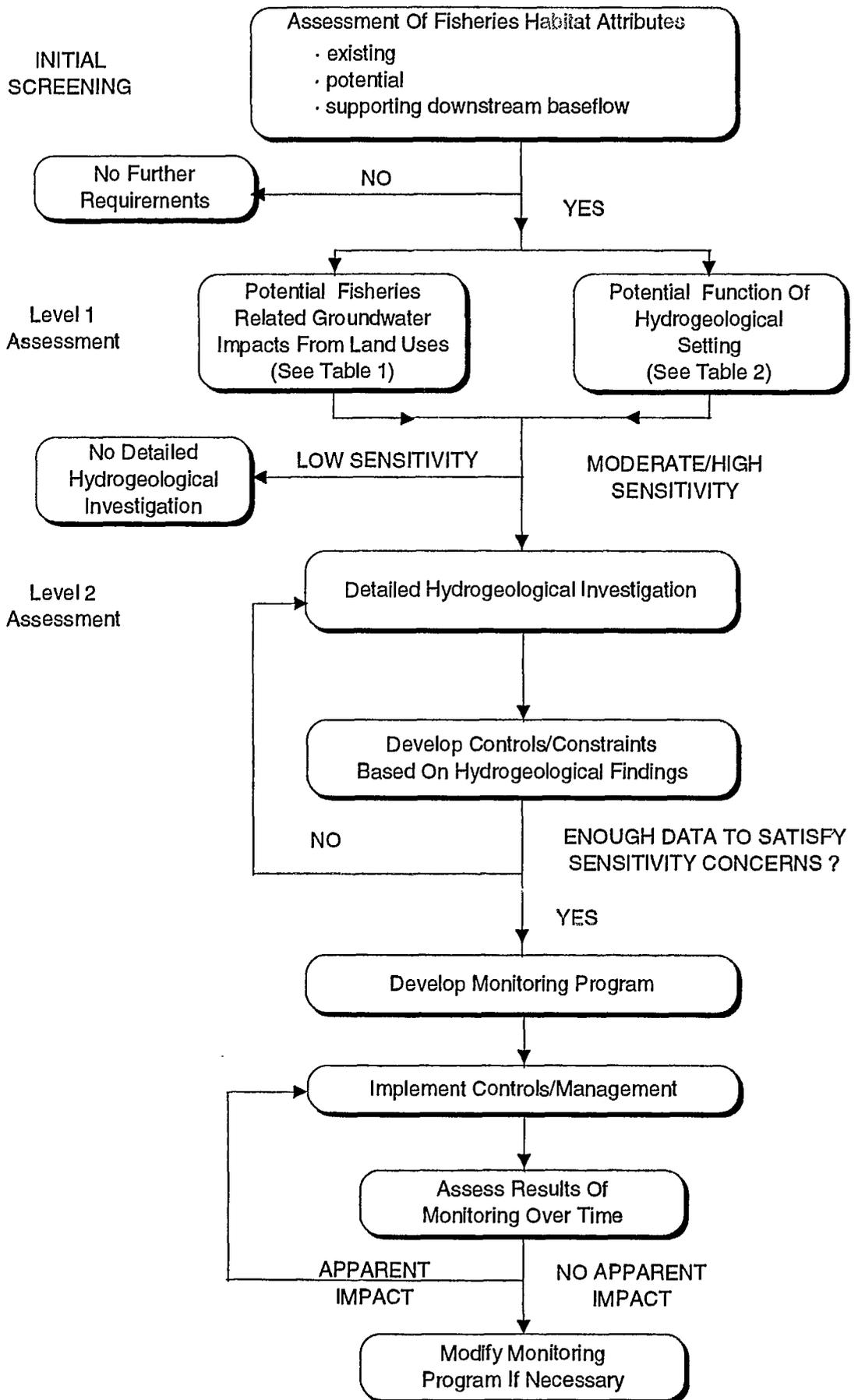


Figure 24. Decision Flow Chart



APPENDIX

Appendix A. Summary of Field Methods

METHOD	PROCEDURE	DATA COLLECTED	OBJECTIVE
1) Seepage meters	<ul style="list-style-type: none"> - temporary 'snapshot' streambed installation 	<ul style="list-style-type: none"> - measure volume of water entering a baggie over a given time to estimate groundwater discharge volume to stream - measure pH, electrical conductivity 	<ul style="list-style-type: none"> - site specific groundwater contribution to surface water and maintenance of baseflow - the areas of significant groundwater discharge to the streambed with respect to fisheries habitat - the relationship of groundwater and wetland areas within the watershed
2) Mini-piezometers	<ul style="list-style-type: none"> - temporary 'snapshot' - 0.5 to 1m depth below streambed in conjunction with seepage meter 	<ul style="list-style-type: none"> - measure the difference between the surface water level and water level in the piezometer to estimate the hydraulic gradient - measure the rate at which an added water level falls by noting time and distance dropped to estimate hydraulic conductivity 	<ul style="list-style-type: none"> - site specific groundwater contribution and maintenance of baseflow - the areas of significant groundwater discharge to the streambed with respect to fisheries habitat - the relationship of groundwater and wetland areas within the watershed
3) Stream piezometers	<ul style="list-style-type: none"> - permanent - 1.5 to 5m depth below streambed 	<ul style="list-style-type: none"> - measurement of water levels within and adjacent to streams to determine fluctuations of water levels over time and in response to storm events - water sample collection and analysis to determine general chemistry and isotope data 	<ul style="list-style-type: none"> - site specific groundwater contribution and maintenance of baseflow - the areas of significant groundwater discharge to the streambed with respect to fisheries habitat - the relationship of groundwater and wetland areas within the watershed
4) Monitoring wells	<ul style="list-style-type: none"> - permanent - well development - drilled to deeper depths 	<ul style="list-style-type: none"> - measurement of water levels to determine fluctuation of water levels over time - water sample to determine general chemistry, quality, and isotope data 	<ul style="list-style-type: none"> - an overall assessment of recharge conditions, including the major recharge areas from both a regional and local perspective

Appendix A. Summary of Field Methods

METHOD	PROCEDURE	DATA COLLECTED	OBJECTIVE
5) Time Domain Reflectometry (TDR)	<ul style="list-style-type: none"> - Installation of soil moisture probes at specific depths in the unsaturated zone 	<ul style="list-style-type: none"> - measurement of volumetric soil moisture content - measurement of bulk soil/water electrical conductivity 	<ul style="list-style-type: none"> - provide soil water balance and infiltration rate data which can be utilized to determine groundwater recharge
6) Aquifer pumping tests	<ul style="list-style-type: none"> - pumping a production well and monitoring water level changes in adjacent monitoring 	<ul style="list-style-type: none"> - water level fluctuation due to the extraction of groundwater which indicates the degree of hydraulic connection storativity and transmissivity 	<ul style="list-style-type: none"> - potential impacts on surface water features as a result of groundwater withdrawal - assessment of hydraulic connection between shallow groundwater and deep aquifers being pumped - quantify
7) Drilling	<ul style="list-style-type: none"> - core samples 	<ul style="list-style-type: none"> - identify geologic materials, distribution, thickness 	<ul style="list-style-type: none"> - refine definition of the hydrological setting - assess permeabilities, and ability to infiltrate to the water table - soil water balances
8) Isotope analysis	<ul style="list-style-type: none"> - draw water from different geological levels 	<ul style="list-style-type: none"> - Identify isotope composition 	<ul style="list-style-type: none"> - characterize groundwater flow paths

Appendix B. Glossary.

AQUIFER

a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients

AQUIFER, confined

an aquifer confined by an 'impermeable' layer above, the aquitard places the fluids within the aquifer under significant pressure

AQUIFER, unconfined

aquifer with upper surface defined as the water table

AQUITARD

a geologic unit with considerably lower permeability than the water bearing material below or above it

BASEFLOW

a component of the hydrologic cycle; the movement of groundwater from groundwater storage (aquifer) to a surface water body (e.g. stream, river, or lake)

DISCHARGE (groundwater)

the movement of water from an aquifer (or saturated zone) across the water table surface. In stream beds this discharge is often referred to as 'upwelling'.

EVAPOTRANSPIRATION

loss of moisture from the earth's surface by means of direct evaporation along with transpiration from vegetation

GROUNDWATER

subsurface water in the zone of saturation where all voids are filled with water

HYDRAULIC GRADIENT

a measure of the decrease in head per unit length of flow path

HYDRAULIC HEAD

the elevation with respect to a datum that water rises to in a tube or pipe that is open to the inflow of water from the adjacent medium at the measurement point

HYDROGEOLOGY

the study of the geologic factors (lithology, stratigraphy, and structure) relating to the nature and distribution of groundwater

HYDROLOGIC CYCLE

the cycle of water movement through the earth-atmosphere system, initiated through the acquisition of water vapour by evaporation and transpiration from water and land surfaces (including vegetation), released into the atmosphere, condenses and is deposited on land by precipitation. At the earth's surface, the precipitation is stored on the surface (lakes, glaciers, etc.) or at depth (groundwater), or is evaporated or transpired to initiate the next cycle.

IMPERMEABLE

the function by which water cannot pass through a soil or rock

IMPERVIOUS

term applied to strata such as clay, shale, etc., which will not permit the penetration of water

INFILTRATION

a component of the hydrologic cycle; the downward flow or movement of precipitated moisture from the ground surface into soil storage, together with associated flow away from the ground surface within the unsaturated zone

PERCOLATION

the downward flow of water in saturated or near saturated soil

PERMEABILITY

the ability for liquid to pass through a medium

RECHARGE (groundwater)

a component of the hydrologic cycle; the addition of water to the saturated zone of water made available at the water table surface, together with associated flow away from the water table to the saturated zone

RUNOFF

general term referring to water running across a land surface, as opposed to running through the soil (throughflow), or through geologic units (groundwater flow)

SATURATED ZONE

zone where all voids are ideally filled with water. The water table is the upper limit of this zone and the water in it is under pressure greater than atmospheric.

SEEPAGE

the slow emission of groundwater at the surface with insufficient volume to constitute a spring

SPRING

natural flow of water from the ground at a point where the water table intersects the ground surface (also see water table)

TILL

heterogeneous, non-stratified sediment deposited by glacial ice. It is characterized by its wide stratum and variable ratio of clay, sand, gravel, and boulders and by its high density.

UNSATURATED ZONE

the zone between the land surface and the water table including the capillary fringe. This zone contains liquid water under less than atmospheric pressure and gasses usually at atmospheric pressure.

WATER TABLE

typically forms the upper surface of the zone of groundwater saturation; above the materials are typically not fully saturated. The water table elevation is controlled by topography, the nature of the near surface materials, and local climatic conditions. If the water table and the ground surface coincide a spring forms. Water table pressure is equal to atmospheric pressure.

WATERSHED

the region of higher ground which lies between two non-communicating drainage systems. It may be regarded as the boundary between two adjacent drainage systems and is synonymous with the term 'divide'.

WETLAND

general term referring to areas exhibiting consistently saturated conditions (i.e. swamp, bog, etc.)

