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Robert Mark Griggs
ABSTRACT

This thesis develops an approach to integrated resources management for hydro-electric energy development and an application of the method to an established single purpose project. Traditionally hydro-electric projects in British Columbia have been orientated towards the single purpose of energy generation. Yet as demands for water-based recreation rise, hydro-electric reservoirs become increasingly valuable for other uses, as has been demonstrated by multi-purpose projects in the United States. Thus, improved planning and management of reservoirs is necessary to achieve an increased level of resource use and environmental quality. It is suggested in this thesis that an analysis of land-use capabilities (biogeophysical) is a logical initial phase in determining the limitations for recreational use at reservoirs. It is further postulated that the use of a methodology which integrates land-use capabilities of the reservoir ecosystem with recreation-user requirements for selected recreational activities will minimize their environmental impact. Such a framework is based on the ecological principle that all land has the inherent capacity to generate different levels of biological production under various combinations of circumstances. Furthermore, based on these combinations of circumstances, the land and water may be classified into distinct landtypes for recreational use.

Such a classification was developed and applied in a case study to Hayward Lake (a Run-of-the-River Reservoir) located near the coast of
southwestern British Columbia. The results demonstrated clearly that the five landtypes (probably generalizable to other reservoirs) were identifiable, and that within these divisions, varying degrees of capability for recreation existed. Within the Reservoir ecosystem, five land-based and water-based landtypes are distinguished. These are the division of the water surface into: 1) the Open Water Zone, and 2) the Littoral Zone, and the division of the land into 1) the Beach Zone, 2) the Foreshore Zone (often preceded by a Subforeshore Zone), and 3) the Upland Zone. These zones may be further classified for selected recreational activities on the basis of various biogeophysical attribute values: e.g., soil textures, slope, water temperature, surface currents, exposure to sun and wind, etc.

The preliminary analysis also indicated that five additional components for integrated reservoir management were necessary, namely: sedimentation control, reservoir clearance, regulated water flows, on-water zoning, and proper design standards. These were discussed briefly in the concluding chapter. In the final analysis, it is suggested that the classification framework should be expanded to assess not only the recreation capabilities of the reservoir (which forms one component of integrated management) but also the total uses of the water resource (based on capability, suitability, and feasibility) for the maximum benefit of society.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Statement of Intent</td>
<td>1</td>
</tr>
<tr>
<td>Thesis Outline</td>
<td>3</td>
</tr>
<tr>
<td>Definition of Terms</td>
<td>4</td>
</tr>
<tr>
<td><strong>CHAPTER</strong></td>
<td></td>
</tr>
<tr>
<td><strong>ONE</strong> THE IMPORTANCE OF INTEGRATED RESERVOIR MANAGEMENT</td>
<td>8</td>
</tr>
<tr>
<td>Integrated Resources Management: The General Concept</td>
<td>8</td>
</tr>
<tr>
<td>Reservoir Management: From Single Purpose to Integrated Use</td>
<td>11</td>
</tr>
<tr>
<td>The Significance of Recreation in Integrated Reservoir Management</td>
<td>15</td>
</tr>
<tr>
<td>Potential Conflicts of Integrated Reservoir Management</td>
<td>17</td>
</tr>
<tr>
<td><strong>TWO</strong> THE RESERVOIR ECOSYSTEM: ITS PHYSICAL PROPERTIES</td>
<td>21</td>
</tr>
<tr>
<td>Development of the Man-made Ecosystem</td>
<td>21</td>
</tr>
<tr>
<td>An Examination of the River Basin Hydrograph and Importance to Reservoir Management</td>
<td>24</td>
</tr>
<tr>
<td>Four Stages in the Life History of Man-made Reservoirs</td>
<td>29</td>
</tr>
<tr>
<td>Reservoir Classes in B.C.: Their Physical Properties</td>
<td>33</td>
</tr>
<tr>
<td><strong>THREE</strong> A METHODOLOGY AND FRAMEWORK FOR IDENTIFYING RECREATIONAL OPPORTUNITIES AND CAPABILITIES OF RESERVOIRS</td>
<td>42</td>
</tr>
<tr>
<td>The Ecological Basis for Land-use Planning</td>
<td>42</td>
</tr>
</tbody>
</table>
The Importance of Soils as a Factor in Land-use Capability

Techniques of Land Classification

The Purpose of the Land Classification Technique

The Reservoir Classification Framework

Step One. Identification of the Reservoir Site Region

Step Two. Identification of Landtypes within the Reservoir Site Region

Step Three. Establishment of Recreation Management Units (R.M.U.)

Step Four. Identification of Land-use Capabilities for Recreation Activities

Degree of Limitations for Recreational Use

Limitations of the Identification Framework

Physical Characteristics of the Reservoir Site Region

Definition of the Site Region

Geography and Hydrology

Climate and Vegetation

Fish and Wildlife

Existing Land Use and Access

The Ruskin Power Development

Landtypes at Hayward Reservoir: The Mapping Procedure

Water-based Landtypes
<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land-based Landtypes</td>
<td>95</td>
</tr>
<tr>
<td>Method for Establishing the Subforeshore, Foreshore and Upland Zones</td>
<td>100</td>
</tr>
<tr>
<td>Discussion of Capability Ratings</td>
<td>102</td>
</tr>
<tr>
<td>Water-based Landtypes</td>
<td>103</td>
</tr>
<tr>
<td>Land Management Policy Recommendation for the Open Water Zone</td>
<td>106</td>
</tr>
<tr>
<td>Land Management Policy Recommendation for the Littoral Zone</td>
<td>109</td>
</tr>
<tr>
<td>Land-based Landtypes</td>
<td>109</td>
</tr>
<tr>
<td>Land Management Policy Recommendation for the Beach Zone</td>
<td>110</td>
</tr>
<tr>
<td>Land Management Policy Recommendation for the Subforeshore Zone</td>
<td>113</td>
</tr>
<tr>
<td>Land Management Policy Recommendation for the Foreshore Zone</td>
<td>116</td>
</tr>
<tr>
<td>Land Management Policy Recommendation for the Upland Zone</td>
<td>119</td>
</tr>
<tr>
<td>Summary</td>
<td>119</td>
</tr>
<tr>
<td>FIVE MANAGEMENT CONDITIONS FOR INTEGRATED RESERVOIR USE</td>
<td>120</td>
</tr>
<tr>
<td>Reservoir Clearance</td>
<td>121</td>
</tr>
<tr>
<td>Sedimentation Control</td>
<td>124</td>
</tr>
<tr>
<td>Regulated Flows for Optimal Water Resources Allocation</td>
<td>128</td>
</tr>
<tr>
<td>Water-surface Zoning and Activity Segregation</td>
<td>130</td>
</tr>
<tr>
<td>The Implementation of Reservoir Zoning</td>
<td>133</td>
</tr>
<tr>
<td>Design Standards</td>
<td>134</td>
</tr>
<tr>
<td>Summary and Conclusions</td>
<td>135</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>APPENDICES</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td></td>
<td>1 The Components of the Basin Hydrological Cycle</td>
</tr>
<tr>
<td></td>
<td>2 Ground Drainage Classes</td>
</tr>
<tr>
<td></td>
<td>3 Classes of Stoniness</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Flood Hydrograph</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Recreational Activities at the Reservoir Site Region</td>
<td>57</td>
</tr>
<tr>
<td>3</td>
<td>Criteria Considered in Rating Capability for the Open Water Zone</td>
<td>68</td>
</tr>
<tr>
<td>4</td>
<td>Criteria Considered in Rating Capability for the Littoral Zone</td>
<td>69</td>
</tr>
<tr>
<td>5</td>
<td>Criteria Considered in Rating Capability for the Beach Zone</td>
<td>70</td>
</tr>
<tr>
<td>6</td>
<td>Criteria Considered in Rating Capability for the Camp Areas (Intensive Use)</td>
<td>71</td>
</tr>
<tr>
<td>7</td>
<td>Criteria Considered in Rating Capability for the Picnic Areas</td>
<td>72</td>
</tr>
<tr>
<td>8</td>
<td>Criteria Considered in Rating Capability for the Paths and Trails</td>
<td>73</td>
</tr>
<tr>
<td>9</td>
<td>The Degree of Environmental Modification Required for Different Recreation Experiences (U.S. Forest Service, 1973)</td>
<td>136-7</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Synthesis of Annual Demand Curve from the Estimated Requirements of the Various Uses for an Integrated-Use Reservoir</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>Model for Multiple-purpose Integrated River Basin Development</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>The Three Major Zones of a Lake (Odum, 1971)</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>Schematic Diagram of the Hydrologic Cycle</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Block Diagram of the River Basin</td>
<td>27</td>
</tr>
<tr>
<td>6</td>
<td>Components of a Hydrograph</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>The Reservoir Site Region</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>Landtypes of the Reservoir Site Region</td>
<td>52</td>
</tr>
<tr>
<td>9</td>
<td>Zonations Within the Littoral Region</td>
<td>54</td>
</tr>
<tr>
<td>10</td>
<td>The Sub-foreshore Zone</td>
<td>55</td>
</tr>
<tr>
<td>11</td>
<td>Daily Demand Curve of an Electrical Utility with Mixed Generation Available</td>
<td>64</td>
</tr>
<tr>
<td>12</td>
<td>Recreation Capabilities: The Foreshore Zone</td>
<td>75</td>
</tr>
<tr>
<td>13</td>
<td>Run-off Characteristics into Stave Lake</td>
<td>83</td>
</tr>
<tr>
<td>14</td>
<td>Reservoir Levels at Hayward Lake (daily)</td>
<td>93</td>
</tr>
<tr>
<td>15</td>
<td>The Foreshore Zone</td>
<td>101</td>
</tr>
<tr>
<td>16</td>
<td>Schematic Drawing of the Sediment Accumulation in a Typical Reservoir</td>
<td>125</td>
</tr>
<tr>
<td>17</td>
<td>Sedimentation Conditions</td>
<td>126</td>
</tr>
<tr>
<td>18</td>
<td>The Components of the Basin Hydrological Cycle</td>
<td>146</td>
</tr>
</tbody>
</table>
LIST OF PHOTOGRAPHS

<table>
<thead>
<tr>
<th>Photograph</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N.E. Area of Site Region. Note steep Subforeshore and Upland Zones</td>
<td>81</td>
</tr>
<tr>
<td>2</td>
<td>N.W. Area of Site Region characterized by steep Subforeshore. Foreshore not shown in photo</td>
<td>81</td>
</tr>
<tr>
<td>3</td>
<td>Mature Conifers among Deciduous Forest Cover, S.W. Shore</td>
<td>85</td>
</tr>
<tr>
<td>4</td>
<td>Private access road along west shoreline. Note reservoir at left of photo</td>
<td>87</td>
</tr>
<tr>
<td>5 &amp; 6</td>
<td>Then and Now</td>
<td>91</td>
</tr>
<tr>
<td>7 &amp; 8</td>
<td>Contrasts</td>
<td>92</td>
</tr>
<tr>
<td>9 &amp; 10</td>
<td>Typical examples of small boulders and stone accumulations along the reservoir shoreline</td>
<td>96</td>
</tr>
<tr>
<td>11</td>
<td>A typical profile of the Subforeshore Zone, N.W. area of Site Region</td>
<td>98</td>
</tr>
<tr>
<td>12 &amp; 13</td>
<td>Examples of the Beach Zone along the N.W. Shoreline. Restricting factors are width and exposure. Note Wet Beach area</td>
<td>107</td>
</tr>
<tr>
<td>14</td>
<td>Wet Beach, bordered by grass covered alluvium sands to left of photo</td>
<td>107</td>
</tr>
<tr>
<td>15</td>
<td>Potential Class I Beach, presently covered by scrubs and grasses</td>
<td>107</td>
</tr>
<tr>
<td>16</td>
<td>The Subforeshore, Foreshore (hidden from view), and Upland Zones</td>
<td>116</td>
</tr>
</tbody>
</table>
# LIST OF MAPS

<table>
<thead>
<tr>
<th>Map</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location of the Study Area</td>
<td>78</td>
</tr>
<tr>
<td>2</td>
<td>Hayward Lake Site Region</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>Existing Zoning</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>Existing Land Use</td>
<td>89</td>
</tr>
<tr>
<td>5</td>
<td>Open Water, Littoral and Beach Zones</td>
<td>97</td>
</tr>
<tr>
<td>6</td>
<td>Subforeshore, Foreshore and Upland Zones</td>
<td>99</td>
</tr>
<tr>
<td>7</td>
<td>Recreation Capabilities: Open Water, Beach and Littoral Zones</td>
<td>104</td>
</tr>
<tr>
<td>8</td>
<td>Recreation Capabilities: Subforeshore Zone</td>
<td>112</td>
</tr>
<tr>
<td>9</td>
<td>Recreation Capabilities: Foreshore Zone</td>
<td>115</td>
</tr>
<tr>
<td>10</td>
<td>Recreation Capabilities: Upland Zone</td>
<td>118</td>
</tr>
</tbody>
</table>
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Finally, to Mr. P. Tattersal, Superintendent of Ruskin Power Development (B. C. Hydro and Power Authority) for his valuable time and assistance in the provision of much of the hydrological data.
INTRODUCTION

The objective of this thesis is to develop a framework that identifies the recreation capabilities of hydro-electric reservoirs and their adjacent shorelines. It is based on the premise that land-use capability is a fundamental starting point in establishing future recreational land management options. In addition, the recreational demands on the limited resource base of the province are increasing at a rate faster than the provision of facilities. These demands, while not directly affecting the recreation capability framework developed in this thesis, nonetheless increase the relevance of the work.

STATEMENT OF INTENT

The interest in this subject was generated by the recognition that hydro-electric reservoirs in British Columbia are primarily oriented toward a single purpose, while other potentially valuable uses of the same resource base have gone undeveloped by the managing agencies involved. This prompted an investigation into the question: could an identification framework be developed that would identify the land-use capabilities for recreation at hydro-electric reservoirs? It is the purpose of this thesis to develop such a methodology that identifies
land-use capabilities for recreation, based on selected biogeophysical attribute limitations, and to illustrate the application of the technique in a case study.

... if the demand for water for recreational purposes continues to rise to the end of the century at the same rate as in the last fifteen years, reservoirs will gather increasing importance as additional recreational resources (Boan, 1969).

This not too surprising fact has already been recognized in the United States. Recreation is incorporated into the overall use of many water impoundments (Reservoirs of the T.V.A., Bureau of Reclamation, and U.S. Army Corps of Engineers), and has proved to be both socially and economically feasible.

The provision of recreational facilities as one component of integrated use in the United States has arisen out of public demand and an increasing awareness that such opportunities exist. The challenge of the federal bureaus involved has been to meet these rising demands, and at the same time, to maintain a desired level of recreational quality. While open space standards have been established and serve as guidelines for recreational densities and spatial layouts of the facilities, few methods have been developed that determine the initial inherent capabilities of the land for sustaining certain types of recreation. For this reason, it is felt that such an identification framework is necessary.

Two additional reasons support capability analysis as a method for establishing future recreational opportunities at reservoirs. Firstly, the classification of land according to land capability is the
logical initial phase in determining maximum resource-use of the land (see Hills, 1961), and also tends to minimize the adverse environmental impacts. Secondly, an approach that incorporates land capability with social and economic realities as governing factors in optimizing land use implies a sustained yield plus maximum social benefits from the land and associated resources.

THESIS OUTLINE

Chapter One of this thesis examines the concept of Integrated Resources Management. It proposes that to increase the net social benefits of man-made water impoundments, the use of reservoirs be expanded to a more integrated use of the same water resource.

The second chapter is introduced by a discussion of the man-made reservoir as an ecosystem. The biological impact of the four stages in developing a hydro project is discussed in addition to a review of the various types of hydro reservoirs in the province. A brief discussion of the operational requirements of hydro projects and their potential for recreational use is also given.

In Chapter Three, the land-use capability identification framework is developed. Four stages are established in identifying land-use capabilities for selected recreational opportunities. The land assessment procedure involves identification and description on a biogeophysical basis of various units of land and water, and an assessment of their land-use capability (based on attribute values) for selected recreational uses.
In Chapter Four, a case study is presented that tests the identification framework. The reservoir examined in light of its land-use capabilities for recreation is Hayward Lake, located in the Alouette, Stave Falls, Ruskin Generating Complex, British Columbia.

The final chapter examines briefly five reservoir management conditions for integrated resource use.

**DEFINITION OF TERMS**

Throughout this thesis, a number of recurrent terms are used for which there is no commonly accepted definition. For the purpose of uniformity in this paper, these terms have been defined as follows:

1. **Recreation.** Recreation is a form of activity in which individuals voluntarily engage in during leisure time (C.L.I. Report No. 6, 1962).

2. **Recreational Activity.** The activities recognized in this study that pertain to man-made reservoirs are grouped into "water-based" and "land-based" activities.

<table>
<thead>
<tr>
<th>Water-based</th>
<th>Land-based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boating</td>
<td>Sunbathing</td>
</tr>
<tr>
<td>- sailing</td>
<td>Gathering and collecting</td>
</tr>
<tr>
<td>- rowing/ paddling</td>
<td>Unorganized games</td>
</tr>
<tr>
<td>- motoring</td>
<td>Hiking</td>
</tr>
<tr>
<td>Water Skiing</td>
<td>Picnicking</td>
</tr>
<tr>
<td></td>
<td>Organized camping</td>
</tr>
</tbody>
</table>
Water-based (cont'd)  Land-based (cont'd)
Fishing       Wildlife viewing
Swimming      Scenic viewing
Wading
Nature study

3. **Recreational Carrying Capacity** is the level of recreational use in man/days per year that can be supported over a specified area, without causing excessive damage to either the physical environment or to the overall satisfaction of the reservoir visitor.

4. **Land-use Capability.** The term land capability refers to the basic ecological principle that land has the *inherent capacity* to produce living organisms of various kinds under various combinations of circumstances (Hills, 1961) without intervention on the landscape by man. This characteristic associated with land is referred to as its "biological productivity" and forms the basis for ecologically sensitive land-use planning. In this thesis, land-use capability considers the interaction of the physical and biological components of the land in determining resource allocations and optimization (see discussion of "optimization," p. 9).

5. **Recreation Capability.** Following from the definition of land capability, recreation capability implies that the various combinations of the biological and physical community interact to produce distinguishable land characteristics, some being more suited to sustain recreational activities than others. In this thesis, land-use capability for recreation refers to the characteristic of the land to
sustain various selected recreational activities on the basis of biogeophysical attribute values (see discussion, p. 59).

6. **Reservoir, and Reservoir Site Region.** The term reservoir refers to a man-made water impoundment. Reservoir in the text of this paper, unless otherwise specified applies only to those reservoirs created for the generation of hydro-electricity. The term reservoir when dealing with its recreational use applies to the total surface area of the impoundment. The term Reservoir Site Region includes the surface area of the reservoir and that land away from the water's edge to either (1) the surrounding height of land or (2) one mile from the reservoir.

7. **Integrated Resources Management,** "... is the application of management strategies to achieve maximum output from the optimized use of natural resources of a specific area for the benefit of a referent group and its successors." (Jeffrey et al., 1969). This type of management objective would suggest that the traditional approach of single purpose resource development be replaced by a more socially desirable set of management alternatives; alternatives that maximize the joint utilization of all resources.

8. **Integrated Reservoir Management,** is the application of Integrated Resources Management to a particular resource: the hydro-electric reservoir. Integrated Reservoir Management implies that reservoirs can serve more than one purpose, provided that proper management objectives are defined. This study examines one component of integrated reservoir use, namely its recreational capability. A project designed
for one purpose but which produces incidental benefits for other purposes should not, however, be considered as an integrated-purpose reservoir. Only those projects which are designed and operated to serve two or more purposes should be described as multiple-use (integrated-use) reservoirs (Hill, 1949).

9. Reservoir Operations Requirements. Hydro-electric plants require certain conditions for their normal operation: drawdown of the reservoir pool, rights of way for transmission lines, the acquisition of land for the generating plant and related facilities, road access, the clearance of floating and subsurface debris, etc. These conditions are referred to collectively as the reservoir operations requirements.
CHAPTER ONE

THE IMPORTANCE OF INTEGRATED RESERVOIR MANAGEMENT

INTEGRATED RESOURCES MANAGEMENT:
THE GENERAL CONCEPT

In the report of the Sub-committee on multiple-use (Jeffrey, et al., 1969), Integrated Resource Management is defined as:

... the application of management strategies to achieve maximum output from the optimized use of natural resources of a specific area for the benefit of a referent group and its successors.

In light of this definition, it is suggested that implementation of such a management strategy would involve four phases:

(a) Defining the geographic area intended to benefit from integrated resources management.

(b) Defining management objectives based on a consideration of referent group needs in the area, as well as outlining the tradeoffs (resource, environmental, social, and economic) between alternative management objectives.

(c) Determining the types of information necessary for rational decision-making by the referent groups for integrated resources management (environmental, economic, social impacts, etc.).
The creation of certain administrative mechanisms that would allow adequate planning and the translation of integrated resources management plans into practice (Jeffrey, et al., 1969).

Since Integrated Resources Management involves the "optimized" use of natural resources, it is suggested that the term "resources optimization" involves the syntheses of two components: (1) determining the capability of the resource base (e.g., its biogeophysical supportive systems under various management objectives, and (2) identifying the values that determine demand for the resource. "Optimization" is therefore the synthesizing and tying together of these components to maximize net social benefits for a referent group. The methodology developed in this thesis examines one aspect of resources optimization: namely, supportive systems (capability) analysis.

Integrated Resources Management is clearly associated to referent group needs and public benefits. This belief is examined by Rowe and McCormack (1970) who suggest that such a resource management policy is fundamentally a social concept.

The idea of multiple use of forest land in North America is modern and popular; it arises not so much from the traditional resource producers--the timberman, the grazier, the hunter--as from the general public as consumers. It appears today as a democratic idea in which the assumption is implicit that the land (particularly the large areas that are publicly owned) has social values that take precedence over the economic interests of the individual producer, or of the single user. As such it is the concern of government responsive to public needs.

It is an important point that in North America "multiple use" is oriented to people, to the public as consumer; it is oriented
neither to the single resource user nor to the tenant or owner as producer. In other words, the idea did not arise as a logical and economically sound proposition for the individual resource developer, but rather as an expression of what citizens believe their country can contribute to the "good life."

This redirected philosophy toward resources management stems from the belief that with increasing size, affluence, mobility, and leisure time of the North American population, the demands upon wildland resources will increase. If such management policies are not implemented, the public enjoyment of wildlands may be pursued at the expense of some resources, thereby continuing the present conflicts between public and private use of the same resource base (Jeffrey, et al., 1969).

These conflicts are well known in British Columbia. The Forest Service has recently begun to adopt similar programs to those of the U.S. Forest Service.

In 1970, as a response to changing times, the Forest Service reassumed a forest-recreation role it had vacated in 1956. This new involvement adds the dimension of people administration to our traditional role of natural resources administration and with the growing public interest in ecology and environmental quality, it is unlikely that we as resource managers will be allowed to conduct our affairs as peacefully as we have in the past. (Marshall, 1971).

The B.C. Forest Service is not the only agency involved with Integrated Resources Management. The recently formed Environment Land Use Committee and Secretariat (1971), while acting as a liaison between various resource departments, is also keenly interested in the concept of integrated resources use and the accruement of maximum public
benefits. Recent studies (Chambers, 1974; Slocan Valley Report, 1974) for selected regions of British Columbia on Integrated Resources Management have arrived at similar conclusions: that Integrated Resources Management increases the net benefits vis-à-vis single purpose management objectives.

The fundamental difference in this redirected approach to resources management is that traditionally resource projects were oriented toward a single purpose: that is, the development and management of the resource for a specific management objective, whereas Integrated Resources Management provides the opportunity for the totality of the resource base to be developed to the maximum benefits of society.

RESERVOIR MANAGEMENT: FROM SINGLE PURPOSE TO INTEGRATED USE

It has been suggested in this thesis that single purpose resource management is being replaced slowly by integrated management: that forest lands are no longer traditionally areas of only timber harvesting, etc. Similarly, it is proposed that man-made hydro reservoirs adopt analogous management policies of integrated use. Such uses would include: sports fisheries, domestic water supplies, hydro-electricity generation, flood control, navigation, irrigation, and recreational uses.

In the past, most developments of water impoundments throughout the world have been initially conceived for a limited number of purposes (Lagler, 1969). In most of these instances, the costs and
benefits for such primary purposes were estimated and evaluated well in advance of the final planning, with the financing of the project based on such costs and benefits (Lagler, 1969).

This single-purpose management objective is still evident in the continuing development of hydro-electric generating reservoirs in British Columbia even though secondary and complimentary uses are now conceived in the initial feasibility studies. The reason for this stems back historically to the development of government bureaucracies. In the past, resource departments have been developed along single purpose lines, with few multi-disciplinary objectives and/or coordinated management with other resource departments (see Power Development Act, 1961; British Columbia Hydro and Power Authority Act, 1962, 1964). This explains in part the slow evolution of Integrated Resources Management, although related philosophies of resources management and forest conservation were practiced in Europe in the 18th century (Murphy, 1967).

Perhaps the most significant breakthroughs in the field of integrated Resources Management and water resource planning have taken place in the United States. These water resource plans were of the individual project type for building small mills or for improving a stretch of waterway for navigation purpose. They were usually single purpose projects, generally undertaken by private individuals (Fox, 1964). With increasing concerns to strengthen national unity, the governments of the day quickly became involved in the field of water resource developments (e.g., the canal building era). The Corps of Engineers also held responsibility during the latter part of the 19th century for improvements of navigation facilities and incidental control of floods. By 1900, many of the ideas
concerning river basin management were incubating. This included the belief that water development and management should be approached on a regional basis. In addition, it was felt that the project by project approach was not effective enough, and that each project be integrated into a total water management scheme (Fox, 1964). The concept of the integrated use of river basins slowly became accepted, as well as the recognition that the land and water resources of the river basin were part of an enormous system. According to G. P. White, the concept of integrated river basin management consisted of three associated ideas: multiple purpose storage reservoirs; the basin-wide program; and a redirected policy towards comprehensive regional development. However, the significant impetus to river basin management and multipurpose (integrated) reservoirs took place during the decade of the 1920's. This period saw three important developments that strengthened the argument in favour of multiple purpose reservoirs (Fox, 1964). These were: a) the passage of the Boulder Canyon Act, providing for federal construction of the first truly large-scale multiple purpose project—the Hoover Dam, b) the adoption of a resolution requesting the Corps of Engineers to prepare comprehensive reports on major river basins of the country, and c) the establishment of the Tennessee Valley Authority (and their policy of treating the river basin as a total unit). In addition, the U.S. Federal Water Power Act of 1920 required consideration of recreation and other beneficial public uses in any plan for improving or developing a waterway (Cooke, 1950).

The Hoover Dam is a significant landmark in that it is the first example of an engineering design which uses a single structure
for a number of integrated uses (White, 1969): irrigation for the Imperial Valley (California); hydro-electricity generation; flood control; and water to the residential, industrial and manufacturing needs in Southern California. While there were numerous small water management projects, with two or three purposes, none were as conspicuous as the Hoover project. By 1940, integrated water resource projects in the United States were the order of the day, with single purpose projects no longer dominant. The Flood Control Act of 1944 reinforced the position that:

... the recreation and conservation values inherent in the development of ... reservoirs should, where practicable, be made fully available for public use, [and that] ... recreation and fish and wildlife opportunities, both present and potential, shall be considered throughout the planning, construction, operation, and maintenance of reservoir projects ... (Dept. of the Interior Information Service, August 18, 1959).

Since World War II, the American model of integrated basin and reservoir management has been applied to some International projects, particularly with United Nations and Food and Agriculture Organization supervised developments (Lagler, 1969). Here the recognition has been that while most reservoirs are conceived for a limited number of purposes, a host of secondary problems arise in connection with the project that have not been adequately provided for. Proper planning action minimizes these secondary problems of economic loss, social disruption, and environmental degradation through the application of integrated management programs. Furthermore, integrated management of a project's facilities may increase the net benefits without a
proportional increase in costs and thus enhance the economic justification for the project (Linsley, Franzini, 1972).

THE SIGNIFICANCE OF RECREATION IN INTEGRATED RESERVOIR MANAGEMENT

Increasing recreation demands, and the overuse of existing recreational facilities are commonplace throughout North America (Clawson, Knetsch, 1966). British Columbia, endowed with the majestic combination of mountains, sea, and lakes, is not without its share of problems in keeping up with its growing recreation demands. Water based recreation is growing particularly rapidly in the province, and shows every indication of increasing at an accelerating rate in the foreseeable future (Parks Branch, 1974; P. Pearse, 1968). As these recreational demands rise, it is evident that water impoundments close to urban areas will become increasingly more valuable in terms of their recreational value.

A decade ago, it was difficult to speak with much assurance on technical and economic aspects of outdoor recreation development at multipurpose reservoirs and farm ponds. Although a great many difficult problems still confront water and recreation resource managers, complete frustration is no longer inevitable or fashionable (Stroud, 1959).

According to Stroud (1959) this has been the result of three significant conservation developments:

a) Improved understanding of the limnology of man-made water impoundments, and their environmental impacts.

b) The development of measurements of the economic value of including recreation at water resource developments.
c) A growing acceptance of recreation as an integrated use of water management by government and private utility companies.

In British Columbia, there are a number of reasons that help to explain the slow acceptance of recreation as an integrated part of water resource projects. In the first place, the vastness of the province's natural resource base has led to widespread confidence in its inexhaustibility.

Secondly, the economic benefits from recreation activities have been difficult to quantify. Eby (1975) suggests, however, that the existence of outdoor recreational opportunities does add to the real wealth of the province, and that the values created by these opportunities are no less real than the more readily measured values of mining, agriculture, and other resource uses (see also Damback, 1956; Knetsch, 1964; Miliken, Mew, 1969; Stone, Friedland, 1972).

Finally, a lack of government coordination and policy has not encouraged integrated uses at water resources projects. The recent formation of the Environment Land Use Committee and Secretariat, and a redirection in the policy of various government departments (notably in the Department of Lands, Forests and Water Resources, and in the Crown Corporation of B.C. Hydro) is changing the philosophy of single purpose to a more holistic approach to water resources management. For the first time in British Columbia, a public utility company (B.C. Hydro) is providing recreation opportunities as an added benefit to hydro-electric generation reservoirs (Buntzen Lake and Seaton Lake, British Columbia, both coastal reservoirs, and land conveyances at the
Arrow Lakes to the B.C. Parks Branch). This is not to suggest that these reservoirs are examples of Integrated Reservoir Management (see definition, pp. 6-7), but only that a redirection in management in response to increasing concerns over resource use is taking place.

POTENTIAL CONFLICTS OF INTEGRATED RESERVOIR MANAGEMENT

This chapter has dealt with the concept of Integrated Resources Management in the general sense, and the significance of integrated use of reservoirs with the emphasis on recreational use (recreation being one component of Integrated Reservoir Management). It has also been suggested that a change in policy is redirecting the focus of reservoirs to adopt additional uses as management objectives. Integrated Reservoir Management, with equal consideration to more than one use, however, is still not evident in British Columbia. As previously discussed, the reasons for this stem back to the evolution of single-purpose bureaucracies and the confinement of existing resource legislation. Because of the multiple concerns associated with the water resource, the initial conflict to be resolved is in the establishment of management objectives, followed by the division of management responsibilities.

Two additional conflicts concerning integrated use must also be resolved. In the first place, related to the question of management priorities, are the functional requirements of integrated reservoir use. Integrated use implies competition for the rights to the use of the same land and water storage. Figure 1 illustrates the estimated
requirements of the various uses at an integrated-use reservoir. It is readily appreciated that integrated planning of a reservoir involves substantially more than the combination of single-purpose elements (see also Figure 2).

Figure 1. Synthesis of Annual Demand Curve from the Estimated Requirements of the various uses for an Integrated Use Reservoir

* Source: Linsley, Franzini (1972).

None of the uses shown is entirely compatible with any other use, although under many circumstances it is possible to bring some of these uses into agreement. The basic factor of integrated-use is "compromise." A plan therefore must be devised that permits reasonable efficiency in operation for each use, although maximum efficiency is not necessarily attained for any single purpose.
1. Multiple-purpose reservoir.
2. Recreation; swimming, fishing, camping.
3. Hydroelectric station.
4. Municipal water supply.
5. City and industrial waste treatment plant.
6. Pump to equalizing reservoir for irrigation.
7. Diversion dam and lake.
8. High-level irrigation canal.
9. Levees for flood control.
11. Regulating basin for irrigation.
12. Wildlife refuge.
13. Low-level irrigation canal.
15. Contour ploughing.
16. Sprinkler irrigation.
17. Community water treatment plant.
18. Navigation: barge trains, locks, etc.
19. Re-regulating reservoir with locks.
20. Farm pond with pisciculture.

Figure 2. Model for Multiple-purpose Integrated River Basin Development
Secondly, integrated use of the water resource places additional strains on the quality of the water. Industrial uses for cooling and consumptive purposes, effluent discharges, domestic use of the water, recreational uses of the water, and water for irrigation purposes, contribute to the overall problem of maintaining a desired level of water quality. In part, this problem can be solved by the initial establishment of the management objectives for the reservoir. For long-term planning of the river basin and reservoir, this final problem must be given considerable attention in that it affects not only the economic components of resources management, but ultimately the more serious consequences of public health and safety.
CHAPTER TWO

THE RESERVOIR ECOSYSTEM: ITS PHYSICAL PROPERTIES

DEVELOPMENT OF THE MAN-MADE ECOSYSTEM

Man-made reservoirs are the result of two distinct ecosystems: the riverine superimposed over the terrestrial. This confluence produces the beginning of a lacustrine ecosystem, the properties of which are readily identifiable and distinct from natural lake ecosystems:

The new ecosystem is a complex hybrid which demonstrates a mixture of characters of the two parent ecosystems both in physical terms as well as in behaviour (Dussart, Lagler, Scudder, Szesztay, White, 1972).

Both contribute to the newly forming lacustrine ecosystem: the terrestrial by its chemical character of the soils and geologic structure being released into the water, and by the riverine supplying the material structure to the newly formed system (i.e., the water) in addition to supplying the community (flora and fauna) that will succeed in the man-made lake.

In the initial filling of the reservoir, most impressive is the sudden beginning and rapid development of the lacustrine system. This is due in part to the release of nutrients from both the submerged organic matter, and the top horizons of the inundated soils. This explosion of nutrients is quickly cycled into primary production (the initial harnessing of solar energy by planktonic algae). This increase
in primary production is transferred through various food chains and is typically followed by a rise in fish production. As the reservoir reaches a more stabilized state, the production of biomass falls greatly and is finally maintained at a lower level. The reservoir begins to exhibit conditions similar to those found in natural lakes. However, significant differences do occur.

**Man-made Versus Natural Lakes**

In the first place, the levels of man-made reservoirs are subject to human manipulation, and therefore do not necessarily coincide with natural run-off patterns. In addition, the "drawing down" (drafting) of water levels in a man-made reservoir is often both much greater and very much more rapid (P. Jackson, 1966) than a natural lake. This often gives rise to a lack of littoral vegetation that is typical of natural lake shorelines. According to Dussart, et al., (1972) the reservoir will be deeper in parts than original maximum river depths, but even the limnetic zones may be virtually stationary and therefore may not support the bitoa normally associated with lenitic habitats. Finally, thermal stratification (the heat budget) and sedimentation in the profundal zone may be markedly different (see Figure 3).

The heat budget of man-made reservoirs depends in large degree upon the current water flow regime developed in them as a result of subsurface inflows and subsurface or surface discharges (B. Allanson, 1973). The design of the dam and location of the penstocks is therefore critical to the degree of thermal stratification (Odum, 1971). Where
Figure 3. The Three Major Zones of a Lake (Odum, 1970)

Water is released from the bottom, as is often the case with dams designed for hydroelectric power, cold, nutrient-rich, but oxygen poor water is released downstream with warm water being retained in the reservoir. The impoundment therefore becomes a heat trap and nutrient exporter in contrast to natural lakes which discharge from the surface and are nutrient traps and heat exporters.

Wright (1967) lists four additional effects to thermal stratification with dams whose penstocks release deep water:

1. Water is released with a higher salinity than would be obtained from surface water withdrawal.

2. Essential nutrients are lost from the reservoir, which tends to deplete the productive capacity of the reservoir while at the same time causing eutrophication downstream.

3. The evaporative loss of the reservoir is increased by the storing of warm water and the releasing of cold hypolimnial water.
4. Low dissolved oxygen in the discharged water reduces the capacity of the stream to receive organic pollutants.

Whether man-made or natural, reservoirs are subject to the ongoing forces of nature, and are influenced directly by the amounts of water inflow from the riverine to the lacustrine ecosystem. The importance of understanding the hydrological interactions within the reservoir ecosystem is essential in assessing future management options of the water resource base. For this reason, consideration is given to the general hydrological characteristics that affect the reservoir.

AN EXAMINATION OF THE RIVER BASIN HYDROGRAPH AND IMPORTANCE TO RESERVOIR MANAGEMENT

An essential component of reservoir management is an understanding of the environmental processes that make up the hydrologic cycle (see Figure 4).

Figure 4. Schematic Diagram of the Hydrologic Cycle

Figure 4 (p. 24) illustrates the processes involved in the transfer of moisture from the sea to the land and back to the sea again and needs little explanation. The river basin (drainage basin), subject to both surface and subsurface water flows forms the logical aerial unit for hydrological analysis. For reservoir management, analysis of the river basin is useful in that one can conveniently draw up a water balance and assess the water resources of the total area.

Two additional factors that are affected by the hydrological cycle must also be recognized by the water resources planner. These are the water balance and the river basin hydrograph.

1. The Water Balance. From a land use perspective, a study of the water balance is important for two reasons. In the first place it ensures:

   ... that the ill effects of wrong systems of land-use do not impair, or lead to less efficient collection and use of a most important natural resource—water (R.G. Downes, 1963).

Secondly, a thorough understanding of the water balance ensures that the ill effects of mismanagement practices of the land will not upset the water balance in such a way as to lead to the destruction of another important natural resource: namely, the soil. This second point needs further clarification. Man's influence on the land is clearly evident, with changes in the water balance being commonplace. These changes in both the water balance and water distribution patterns have not been without adverse environmental impacts. Some of the more familiar consequences include: increasing aridity in certain parts of
the world, surface deposits of salt, soil erosion and deposition, and water logging (ponding).

According to R. More (1969), the river basin cycle (or transfers of water in the basin) may be viewed simply as:

... inputs of precipitation (p) being distributed through a number of storages by a series of transfers, leading to outputs of basin channel runoff (q), evapotranspiration (e) and deep outflow of ground water (b).

The general operation of the basin hydrological cycle may be simplified as follows:

Precipitation = Basin channel runoff + Evapotranspiration + Changes in Storage

Figure 5 illustrates in more detail the features of the river basin.

2. The River Basin Hydrograph. The amount of water storage within a reservoir is determined chiefly by the quantity of runoff from the river basin, which in turn is a function of the effective precipitation of the region. The runoff is that residual of the precipitation which flows into a surface stream. In other words, it is:

... that portion of precipitation which reaches a natural channel after loss by evaporation and transpiration, and after soil moisture deficiencies have been satisfied (D. Mackay, 1969).

To reach the channel and ultimately the reservoir, the water moves above and through the ground. Its movement is influenced and regulated by such factors as landforms, soils, vegetation and man's activities (see
where:  
\( p \) = precipitation  
\( m \) = through flow  
\( s \) = seepage  
\( q_0 \) = overland flow  
\( G \) = ground water storage  
\( G' \) = deep storage  
\( R \) = surface storage  
\( S \) = channel storage  
\( M \) = soil moisture storage  
\( L \) = aeration zone storage  
\( q \) = basin channel runoff  
\( l \) = interflow  
\( f \) = infiltration  
\( d \) = ground water recharge  
\( g \) = baseflow  
\( b \) = deep outflow  
\( d \) = deep percolation

Figure 5. Block Diagram of the River Basin

(See also Appendix 1, the Schomatic Inter-relationships of the Basin Components).

Table 1 below). Continuous monitoring of this runoff measured over time results in a graph of flow called the hydrograph (see Figure 6).

During dry periods, the flow of the river naturally decreases. This base flow continues until precipitation (rain) falls at which point the discharge rate increases rapidly to a peak. The peak is usually reached shortly after the rain has ceased although the time lag depends upon local physiographic and climatic conditions. The amount of flow is therefore largely determined by the amount of moisture not retained.
<table>
<thead>
<tr>
<th>Influencing Factors</th>
<th>General Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The Basin Area</td>
<td>The greater the catchment area, usually the higher the peak discharge.</td>
</tr>
<tr>
<td>2. The Basin Shape</td>
<td>Length and width of the basin affect the travel time of the surface and subsurface flows to the main channel of the river.</td>
</tr>
<tr>
<td>3. Basin Elevation</td>
<td>Elevation is a function of effective precipitation, and influences vegetation, soil types, etc.</td>
</tr>
<tr>
<td>4. The Drainage Network</td>
<td>Different patterns of drainage can impact the magnitude and shape of the hydrograph, (i.e., a quick rise in the hydrograph is an example of a well-drained network of short, steep gradient streams).</td>
</tr>
<tr>
<td>5. Basin Slope</td>
<td>Affects discharge rates of the water into the reservoir, and is closely related to basin shape, and local drainage patterns.</td>
</tr>
<tr>
<td>6. Climate</td>
<td>Influences the availability of precipitation, evapotranspiration, the amount of water held in ground storage, snow pack, etc.</td>
</tr>
<tr>
<td>7. Vegetation and Land-use</td>
<td>Vegetation or lack of, can impede or increase surface runoff, and affect the degree of surface and subsurface erosion. Forest removal has been shown to increase surface runoff, with a marked shift of the hydrograph to the left, and an increase in its magnitude.</td>
</tr>
</tbody>
</table>
Figure 6. Components of a Hydrograph

The shape and magnitude of the hydrograph, which is useful in predicting the total available volume of water discharged in the river basin, is influenced by a number of factors. While these factors are only given brief mention in statement form, it is well to remember that each should be considered in light of its restraints to integrated use of the river basin. The influencing factors on the hydrograph are listed in Table 1 (p. 28).

FOUR STAGES IN THE LIFE HISTORY OF MAN-MADE RESERVOIRS

Four stages have been identified (Dussart, et al., 1973) in the history of a man-made reservoir:

(1) feasibility studies, and consideration of alternative plans,
(2) planning and construction,
(3) initial filling and stabilizing of the reservoir,
(4) stabilized (lake management stage).
The final phase is sedimentation of the reservoir and a return to the riverine environment. The control of this process is discussed in more detail in Chapter Five, Management Conditions for Integrated Reservoir Use. The salient points of each stage are briefly discussed below.

(1) **Feasibility Studies.** The first stage is characterized by a series of impact studies: from prefeasibility to final design plans. While the emphasis in the report is on the biological implications of creating a reservoir (i.e., the effects on the terrestrial and aquatic organisms) during this stage, most preliminary studies are concerned with the technical aspects of the dam, developable storage of the reservoir, and the physical characteristics (geology and topography) of the site. Geology and topographic conditions are also important determining factors in the location of the dam. These initial studies are followed by economic studies, the feasibility of alternative sites (technical and economic aspects), and finally, preliminary design studies.

(2) **Planning and Construction.** During the second stage, the main features of the project are finalized and construction is begun. This stage is particularly important in that the new biotic community can be planned for. This can be accomplished in part by preparation of the lake bottom which is essential for a number of reasons.

(a) In the first place, the installation of cover or spawning beds may be provided for preferred fish species (Lagler, 1968; P. Jackson, 1966).
(b) Secondly, reservoir clearance adds to safety and convenience in both navigation, commercial fisheries, and recreation.

(c) Finally, preparation of the future lacustrine bottom reduces the possibility of health hazards from disease vectors (Dussart, et al., 1972).

Throughout the construction of the dam, serious ecological consequences can result, particularly with respect to the migration of anadromous fish species (W. Hourston, 1958). For this, and other reasons, the timing of the various stages in the construction of the dam is crucial. Consideration of these problems should be given adequate attention, in that left unchecked, they develop into a host of secondary related problems that affect integrated use of the reservoir (Midgely, 1971).

(3) Filling and Stabilizing. The third stage is characterized by filling of the reservoir, and its "progression" to stabilization. The filling stage is important for two reasons, as both technical (operational) and biological considerations should be carefully monitored. The technical considerations insofar as impoundment of the water behind the dam regulates and changes the flow of water downstream. From an operations view, this naturally affects the degree to which downstream sites can function effectively in the production of hydro-electricity. This often causes increased demands on the downstream reservoirs and results in greater drawdowns, the consequences of which affect both the biological community and aquatic vegetation in the
marginal areas of the shoreline (P. Jackson, 1966; W. Hourston, 1968), in addition to the public use of the reservoir.

During filling and stabilizing, the biological system must also be closely monitored, for it is during this stage that various species may be encouraged or suppressed. In some instances, "rescue operations" have been carried out for organisms that have been threatened by drowning. Such action is often unjustified, with the exception of non-mobile rare species, and in some cases, has not demonstrated to be biologically successful (Dussart, et al., 1972).

In the initial filling, the reservoir is characterized by a rapid increase in biological production (i.e., planktonic blooms) caused by nutrients being released from the flooded substrate. This is followed by the rapid establishment of aquatic vegetation and organisms, including fish (P. Jackson, 1966). A decline from this high level of productivity usually follows due to nutrients being taken up by the aquatic vegetation in addition to downstream loss. Upon filling of the reservoir, the shoreline benchmark is established, and through a complex series of interactions, the shoreline gradually becomes stabilized. Aquatic plants and animals along the shoreline and in the littoral zones are usually maintained with great difficulty at man-made reservoirs (E. Vernon, 1958). This is due to the plants and animals being subjected to submersion to great depths, to exposure with consequent dessication and freezing, and to physical damage by wave action.

(4) Stabilized. The stabilized state of a man-made lake is reached when:
... fluctuations in its biological parameters of production exceed only little, if at all, those in a natural lake of similar physical characteristics and like latitude and elevation (Dussart, et al., 1972).

Stabilization would also be characterized by a seasonally cyclic balance in the oxygen balance of the lake. In an idealized state, the biological stabilization of the reservoir would be thought to occur when an equilibrium between mortality and natality of the organisms in the system is reached, and when the species and community make-up of the system becomes relatively fixed. However, even natural lacustrine systems are far from being biologically stationary. Consequently, wide fluctuations may occur in abundances of organisms from year to year, even though the productivity characteristics (total biomass) remains fairly constant. This is also typical of reservoirs where similar patterns of fluctuation are exhibited. Stability of a reservoir ecosystem is therefore a relative matter, with full stabilization never being assured.

RESERVOIR CLASSES IN B.C.: THEIR PHYSICAL PROPERTIES

Hydro-electric developments in British Columbia may be classified into three (3) distinct groups, (storage, run-of-river, and diversion reservoirs), each with an established set of operations requirements, damsight characteristics, and identifiable reservoir features.

This section deals briefly with the different classes of reservoir with emphasis on how site characteristics and operations influence the degree to which integrated reservoir management can be incorporated.
into the overall project. Such a discussion cannot avoid the use of generalizations. Unfortunately, the use of such generalizations also invites misrepresentation of the facts, if not interpreted with extreme caution. For this reason, the statements made in this section on the nature of reservoirs should not be taken out of context, nor applied to specific cases, as topography and climate within the province provide a wide range of reservoir morphologies.

The Storage Reservoir

A storage reservoir is one where the size of the impoundment is of sufficient size to permit carry-over storage from the wet season to the dry season, and "thus to develop a firm flow substantially more than the minimum natural flow" (R. Linsley, J. Franzini, 1972). They are therefore used to augment the flow between both high and low years of runoff as well as between seasons within a year, while maintaining efficient power generation at the damsite and at sites further downstream. In British Columbia, this type of reservoir is most common (in acre/feet of water stored). Storage reservoirs can be further classified into three (3) categories: the cyclic operations reservoir; the normal annual refill reservoir; and the coastal reservoir.

(a) The Cyclic Operations Reservoir

Cyclic reservoirs bulk large with their prime function being to augment the flow of the river during dry seasons. The principal factor

1 Information for discussions with Senior Energy Management Engineer, B.C. Hydro and Power Authority, Vancouver, B.C.
that isolates the cyclic reservoir from other storage reservoirs (in addition to size), is their drawdown characteristic. Cyclic reservoirs release water (and at the same time generate electricity), to even out the flows from the river basin. The drawdown of the reservoir is dependent upon local surcharge conditions, and is a reflection of weather patterns. Due to the large storage capacity of the cyclic reservoir, the pool is seldom drawn down to the minimum level. However, where inflow is low one year, and with water requirements remaining constant downstream, the pool level is naturally drawndown. Because the "surcharge period" (the period of time required to refill the reservoir to operational pool levels) is often greater than one year, continual low-water years result in increasing drafts of the reservoir, with the refill period being extended further onto the time horizon. For integrated use of the reservoir, this presents serious problems in that not only are large, unaesthetic and unuseable parts of the shoreline exposed, but use of the reservoir for navigation (e.g., log booming and recreational boating) becomes increasingly difficult and hazardous.

Once the cyclic reservoir is under normal operations, given a series of average climatic years, expected drawdowns are not large. From a recreational standpoint, this is advantageous in that beaches and shorelines become stabilized and are more usable. With the shoreline benchmark well established, proper clearance of stumps and trees can also be undertaken in accordance with the objectives of the integrated management policy for the reservoir.
(b) The Normal Annual Refill Reservoir

The second type of storage reservoir is the normal annual refill reservoir. The main distinction between this and the cyclic reservoir is the drawdown component. As the term would suggest, annual refill implies that the water level is drawn down annually to some minimum level, though not necessarily to the dead storage. Annual refill reservoirs are correspondingly smaller than cyclic reservoirs, and are able to surcharge in one year. They are governed by a basic annual rhythm of rise and fall, somewhat as follows:

(1) A peak flood flow - usually in late spring.

(2) A somewhat irregular decline in flow over the following frost-free months--varying with local precipitation and temperature.

(3) A continuing decline of a more uniform character with the onset of freezing winter weather as streamflows become almost entirely dependent on groundwater storage--until the annual minimum flow is reached in late winter or early spring.

(4) The start of an upward trend, gradual at first as the warming temperatures of spring take effect, then more rapid as snow melts and rain falls until the peak flood arrives to start the cycle over again (Sexton, 1974).

The pattern is changed for those rivers on the west coast that drain the Pacific slopes of the Coast Mountains. These rivers are rain-charged which causes the high flows to occur in winter and the lows in
summer. Most annual refill reservoirs are classed as snow-melt reservoirs and are influenced by the former characteristics. They are refilled during the spring and summer, and drafted during the fall and winter months. Depending on the available storage capacity of the river basin, the annual refill reservoir carries the same function, though on a smaller scale, as the cyclic reservoir; that of averaging the outflow between minimum and maximum flow periods.

Local climatic conditions and upstream operations can affect the degree of drawdown on the reservoir. Fluctuations can vary from a few feet on a daily basis to over seventy feet from season to season. Such fluctuations have caused considerable concern with local residents.

Where a cyclic reservoir does control the headwaters of a river, downstream annual reservoirs can become extremely predictable in their drawdown characteristics, although other variables must also be considered. Where such predictability occurs, future land management can be planned and provided for. This is particularly significant where recreation options are available. As most surcharging of the reservoir usually takes place during the early summer, with the maximum pool levels being reached in July-August, this coincides with summer demands for water-based recreation. Because of this predictability, annual refill reservoirs become increasingly attractive for other integrated uses. Clearance programs are also more easily managed and can be planned and undertaken during certain periods of the reservoir schedule. Shoreline and aquatic vegetation adapts more readily to the routine pattern of drawdowns than the irregular cyclic reservoir scheduling. Furthermore,
the annual refill reservoir tends to exhibit characteristics similar to natural lakes in its discharge and refill characteristics.

(c) The Coastal Reservoir

The coastal reservoir is the smallest type of storage reservoir in British Columbia. It is distinguished by two characteristics: a small storage capacity, and a large inflow of water (rain-charged) in the river basin. During a few periods of the year, there is often more water flowing into the reservoir than power generating demands require. Consequently, the reservoir pool is held full by spilling the excess water, and drawn down by generation. In loose terms, these reservoirs are referred to as "fill and spill" reservoirs in that they fill and spill more than once a year.

Fill and spill reservoirs are influenced directly by local climatic conditions and are subject to immediate drafting when precipitation is prolific in the catchment area over a short period of time. This is due to the lead-time between precipitation and inflow into the reservoir being relatively short.

Because the coastal fill and spill reservoirs are subject to local climatic conditions and often need to spill with little warning, their recreational capability is not as high as the annual refill reservoir where predictions on drawdown can be made. In addition, due to the irregular drawdown and refill characteristics, there is not always an established shoreline as the pool level is constantly fluctuating. This influences not only the recreational use of the shoreline and littoral zones, but also the establishment of a well-defined biotic and limnetic community.
The Run-of-river Reservoir

Next to storage reservoirs in British Columbia, run-of-river plants are most common. Like the storage reservoir, they too withhold and then release water down the natural river bed after using the developed head to generate electricity. However, the main difference with the run-of-river system is that generally it has very limited storage capacity due to the surrounding topography (steep, narrow valleys), and can only use water as it comes. Nearly all run-of-river reservoirs therefore, are suitable only on those streams that already have a sustained flow during the dry season. This means that run-of-river plants rely almost entirely on upstream reservoirs (cyclic storage and annual refill reservoirs) to even out the flow for their use.

Because run-of-river plants have little or no storage, they also rely on the natural storage of the river to supply a head of water. Consequently, the drawdown on run-of-river reservoirs is of minor importance and maintains a fairly constant level. From the operations perspective, this is desirable in that the higher the head, the greater the efficiency of the plant.\(^2\) Equally desirable from the recreational side are the regular pool levels, the advantages of which have been discussed in the previous section. While run-of-river reservoirs are not large, they are often located in narrow river basins with relatively

\(^2\) Power operation efficiency versus the level of the reservoir depends upon the design of the generators, etc. Usually a small drop in water level does not significantly affect power generation.
lower gross heads than other streams, hence the lack of available storage capacity.

Due to the steep valley walls that encompass many run-of-river projects, the reservoir pools are also fairly narrow in dimension. Where the volumes of inflow are sufficiently large, the problems of surface currents in the reservoir can arise. This can impede both recreation and navigation on the reservoir where currents are strong. The dynamics of river flows (in straight channels) are such that the fastest flows are in the middle of the river and at the surface, while the shoreline and bottom of the river retard the flow (Wunderlich, Elder, 1973). For recreational use on or near the shoreline, reservoir currents may not be serious. Use of the reservoir, however, on the open water zone, where currents are apt to be faster, might require segregation and supervision, but would depend upon the nature of the activities. In general, run-of-river reservoirs provide for a wide range of Integrated Reservoir Management practices, although each project must be judged on the basis of its specific characteristics.

The Diversion Reservoir

The third and final type of reservoir in the province, while not as common as the storage or run-of-river reservoir, nevertheless displays characteristics similar to the former. Diversion reservoirs differ from the storage reservoir only by the simple feature that whereas the storage system stores and releases water down the same river basin, the diversion reservoir stores and then diverts the water through a series of penstocks into another river basin. The reason for this
diversion is often to augment the flow of the second river basin, as well as to generate electricity in the diversion process. In this fashion, the water can be used more than once.

Diversion reservoirs tend to be small in nature (less than 200,000 acre/feet), are usually part of older power systems, with the reservoirs exhibiting stabilized characteristics. For this latter reason, diversion reservoirs are more suitable to integrated uses in that the shorelines are well established, clearance programs have often been initiated, plus the generating capacities are relatively smaller, with increasing power demands being met by the larger developments in the interior of the province. This would imply that control of the pool levels for public use could be made possible, even at the expense of power production cutbacks. Theoretically, the losses from these smaller plants could be offset by the social and economic benefits of including recreation as part of the integrated reservoir management plan (see discussion, Chapter Five).
CHAPTER THREE

A METHODOLOGY AND FRAMEWORK FOR IDENTIFYING RECREATIONAL OPPORTUNITIES AND CAPABILITIES OF RESERVOIRS

THE ECOLOGICAL BASIS FOR LAND-USE PLANNING

Man does not seem to be able to understand a system he did not build and, therefore, he seemingly must partially destroy and rebuild before use limitations are understood. (Leopold, 1941).

It is perhaps unfair to criticize past actions on the basis of present knowledge, although we have ample cause to regret them because of the costs to correct mistakes. (S. Cain, 1968).

As society increases its alarming rate of non-renewable resources consumption, a more conscientious effort must be given to the environmental side-effects and future consequences if present trends continue. Today, with the available technologies, it is unreasonable not to manage lands in such a manner so as to avoid massive soil erosion: to protect watersheds and manage water resources so as to maintain water quality and avoid flooding: to maintain productivity within forests and grasslands: and to manage fish and wildlife in a way that they will continue to supply us and give us pleasure (Cain, 1968). The knowledge that permits such sound land management practices stems from all the natural sciences: from geology, soils, climatology, geography, as related to living natural resources: from botany and zoology, with their many related sub-divisions, and from physics and chemistry, "especially as they bridge the life sciences through biochemistry and
biophysics" (Cain, 1968). Yet important as they are, these scientific disciplines are essentially too analytical and compartmentalized, with few interdisciplinary exchanges. If a comprehensive understanding of nature is desired it is suggested that these specialized disciplines must work together. The role of ecology, therefore, is the development of a synthesis, that draws together the processes and conditions of nature and the interrelations among them. As Odum writes (1971), ecology is "the study of the structure and function of nature." Ecology as it pertains to land-use therefore must consider such concepts as: nutrient cycling, ecological niches, productivity, and energy transfers, with man, not as the centre force, but functioning only as one part of nature.

Biological and ecological systems are sustained primarily by solar and geothermal energy. This energy is stored by photosynthetic and chemosynthetic activity and transformed into organic substances—chiefly by green plants (Odum, 1971). For resource management purposes, the most efficient long term energy utility occurs under natural conditions (Watt, 1968; Spencer, 1972). This suggests that modifications of an ecosystem cause a reduction in primary production. Land management should therefore coincide closely with the natural supportive systems of the environment, thereby maximizing and optimizing on the resource productivity of the ecosystem. Accepting this premise, resource evaluation should be based initially on the inherent characteristics of the land: its natural capability to produce various living organisms of various kinds under various combinations of circumstances (Hills, 1961). This characteristic is referred to as "land capability," and it is the
fundamental starting point in evaluating land in terms of its natural productivity. In this thesis, the concept of land capability is applied to the development of a land classification technique for recreation on man-made hydro reservoirs.

THE IMPORTANCE OF SOILS AS A FACTOR IN LAND-USE CAPABILITY

From the discussion above, it is suggested that an assessment of local soil conditions within well-defined, and readily identifiable landtypes of the reservoir region, will provide much information necessary to identify recreational capabilities at any particular site. While soil assessment is primarily directed toward land-based recreation activities, its importance can also be recognized in the identification of capabilities within the littoral zone of the reservoir, where surface bottom, texture, etc., are important limiting factors. The parameters of aquatic conditions, and operational requirements of the hydro plant must additionally be considered in evaluating open-water zones of the reservoir.

"Soil" refers to all of the unconsolidated materials covering the earth's surface--the regolith. As used in this paper, the "soil" refers to that portion of the regolith that has had some form of soil processes take place. These soil processes are the result of five factors of soil formation, the classical equation being:

\[
\text{Soil} = f (\text{Parent material, Climate, Biota, Relief or topography, and Time}).
\]
The soil is a dynamic resource that has seldom been given due recognition in the past as an influencing factor in determining land management options. Yet the soil is an irreplaceable resource, and as pressures upon land increase, this resource becomes more and more valuable.

A need exists therefore, in any comprehensive regional planning program to examine not only how land and soils are presently used but how they can best be used and managed. This requires an areawide soil survey which shows the geographical location of the various kinds of soils, identifies their physical, chemical, and biological properties, and interprets these properties for land use and public facilities planning (I. Bauer, 1966).

Soils assessment is important in that it provides data for defining and classifying each soil, as well as making predictions as to the behaviour of soil under specific land management. The properties of soil can then be used to determine the type, location, and degree of recreational activities within specified "landtypes."

The term "landtype" suggests that land may be classified into identifiable components, based on selected criteria. The following section is therefore devoted to a brief examination of various land classification techniques, with the purpose being to synthesize aspects of each technique into a land classification framework for man-made reservoirs.

TECHNIQUES OF LAND CLASSIFICATION

This thesis adopts the definition by G. A. Hills (1970) that land classification involves various processes which:
identify, describe and name areas in terms of their natural features without attempting to rate them.

Hills' classification of terrestrial areas is based on the perceivable features of both vegetation and physiography, where the total site classification involves the subdivision of land into: site regions, landtypes, and physiographic site types (see later discussion).

According to Mabbutt (1968) there are at least three (3) approaches to land classification: the genetic, where land is subdivided into natural regions on the basis of causative environmental factors (i.e., climatic regions); the landscape approach, where land is subdivided on the basis of different land forms, soils, and vegetation (at the level of visual experience); and finally, the parametric, which subdivides and classifies along gradients of selected attribute values (i.e., moisture regimes).

Whatever the approach, land classification is the first of many processes in the assessment of man's possible use of the land for agriculture, forestry, recreation, mineral extraction, ecological preserves and so on. While the classification processes depend upon natural features of the land, or the environmental components (its geological productivity for example), the next stage in determining land use involves "land evaluation"; its suitability and feasibility (Hills, 1970), and implies manipulation of the natural system by man; the use of technologies, finance, labour, and inclusion of social parameters. While land classification suggests a permanent classification based on the relative self-perpetuation and equilibrium of the environment under climax conditions, the concept of land evaluation suggests
less permanence as societal goals and values and the technology developed to achieve them changes over time. According to Stewart (1918):

Land evaluation is not something that can be done once and for all time, but must be repeated when significant changes take place in any of the human resources.

THE PURPOSE OF THE LAND CLASSIFICATION TECHNIQUE

Outdoor recreational planning should require a comprehensive environmental assessment to make full use of, and to be compatible with, environmental conditions (Morton, Fox, 1975).

This means that any biogeophysical assessment of a region should indicate where the local conditions will hinder or aid specific development. It should also include the potential environmental impact of specified recreational uses at the site. Failure to meet these conditions can result in overuse, or misuse of the land, and an increase in environmental deterioration. Proper land management with an appreciation of the ecosystem bypasses the more common phenomena related to mismanagement land practices. Finally, the classification of the land into its biogeophysical components provides the background data necessary to make further decisions with respect to land use, and can be applied in conjunction with the economic, social, and political parameters that are also required in formulating a comprehensive land management plan.

THE RESERVOIR CLASSIFICATION FRAMEWORK

The classification system developed in this thesis combines the genetic, landscape and parametric approaches to resource classification
and includes as part of these approaches the method developed by Hills (1970) as "The Classification and Evaluation of Land for Biological and Graphical Production." The significance of Hills' approach is that it enables the continuous mantle of the earth to be subdivided into physiographic site units "suitable for studying specific relationships between the physiographic environment and the series of biotic communities which it supports" (Hills, 1970). Hills' approach involves the subdivision of land into three distinguishable categories based on the three approaches to land classification outlined above. These are the division of land into:

1. **The Site Region**, which is an area within which "similar combinations of relief and parent soil material have similar climate and consequently a similar succession of plant communities." (The Genetic).

2. **The Landtype**, which is a subdivision of the Site Region based on recognizable features of:
   (a) Landform
   (b) Soil texture
   (c) Mineral composition of bedrock
   (d) Depth of parent soil material
   and includes the microclimatic features of the site region to the three landform features. (The Landscape).

3. **Physiographic Site Type**, which is a subdivision of landtypes based on:
   (a) Moisture regime
(b) Local climate

c) Significant variations in soil depth more specific than those which characterize the landtype. (The Parametric).

Thus in adopting the assessment procedure outlined above, the following four stages have been established in identifying the land-use capability for selected recreational activities:

(a) Identification of the Reservoir Site Region
(b) Identification of Landtypes within the Reservoir Site Region
(c) Establishment of Recreation Management Units (R.M.U.)
(d) Identification of landuse capabilities for recreational activities.

Finally, in this chapter, various criteria are established that can be used to identify the degree of limitation that Recreation Management Units have for selected activities. The degree of limitations are rated: None to slight (Class 1); Moderate (Class 2); Severe (Class 3).

In summary, the land assessment procedure involves two components:

1. the identification and description, on a biogeophysical basis, various units of land and water, and
2. the assessment of these blocks for specified recreational uses based on attribute values.

Step One. Identification of the Reservoir Site Region

Step One involves the establishment of (a) the surface area and (b) the land area of the reservoir site region. Extent of the reservoir includes that surface area up to the maximum pool level. The site region
includes the surface area of the reservoir and that land away from the water's edge (at maximum level) to either (1) the surrounding height of land, or (2) one mile from the reservoir. The figure of one mile has been selected on the premise that most recreational activities centred around water bodies (camping, picnicking, play areas, etc.), usually are located within this distance from the shoreline.

The location of the dam establishes the downstream limit of the Reservoir Site Region (see Figure 7). The scale of the mapping for the Reservoir Site Region naturally depends upon the size of the reservoir being examined and the degree of detail that is to be shown.

Figure 7. The Reservoir Site Region
Step Two. Identification of Landtypes within the Reservoir Site Region

"Landtypes" within the Reservoir Site Region form the basis for land-use classification, and are recognized by distinctive physiographic features. These features are the result of interactions between three components of the environment, namely:

- the topography
- the soil characteristics
- the vegetation.

The interaction of these three components produces five distinct zones (Jaakson, 1970, 1972) specific to reservoirs and their adjacent shorelines. They are:

(a) The Open Water Zone
(b) The Littoral Zone
(c) The Beach Zone
(d) The Foreshore Zone
(e) The Upland Zone.

Examples of the different combinations of landtypes can be diagramatically shown as follows (see Figure 8).

**Definition of Reservoir Zones**

(a) The Open Water Zone

The Open Water Zone refers to the total water surface area of the reservoir extending from the five-foot contour interval of the Littoral Zone (see definition below). As discussed later, the principal activities in this zone are related to boating. Because of the nature of
Figure 8. Landtypes of the Reservoir Site Region
these activities, strict regulations need to be adopted in order to ensure maximum public safety. The control of these activities can be made more plausible by relating the dimensions of this zone to the lake morphology. "Whereas a round lake renders activity control difficult, a lake with bays and headlands makes activity segregation easier" (Jaakson, 1972). The water surface can also be classified into three "activity zones" for those lakes where the management objective is to minimize incompatible on-water activities (see p. 130).

(b) The Littoral Zone

This zone is defined as the area, below water, from the water's edge to the five-foot depth contour. This contour is of significance for recreation since it forms the limit where most swimming, wading, and other activities take place. Due to the nature of reservoirs and their characteristic of pool level drawdowns, it is important to recognize that the Littoral Zone is variable in size. During periods of minimum water level, the Littoral Zone can be divided into the "low water zone" (area from the water's edge up to the five-foot contour depth), and the exposed "wet beach" (area from the water's edge up to the high water mark, see Figure 9). At periods of maximum water level, the extent of the Littoral Zone remains at the five-foot depth established at minimum level (the permanent Littoral Zone), although the new five-foot depth is now closer to the shoreline.

(c) The Beach Zone

The Beach Zone is defined as the area above the water's edge (from the maximum high water mark), to the first significant change of
slope, and/or beginning of terrestrial vegetation. Beach gradients can range from 2-15% with beach materials varying from fine sands (no limitations for recreation), to sharp, unsorted rocks (severe limitations for recreation).

(d) The Foreshore Zone

The Foreshore Zone is defined as that area extending inland from the Beach Zone to the beginning of the Upland Zone. This zone includes a range of slope conditions to a maximum of 15%, with varying degrees of vegetative cover and soil conditions. In some instances where the Beach Zone is absent, the Foreshore and/or Upland Zone may begin at the water's edge. Where terraces are evident along the valley sides, a steep, often heavily eroded bank (slope >15%) may rise from the water's edge preceding the Foreshore Zone. This zone (usually less than 1000 feet) is referred
to as the "sub-foreshore" and can be rated according to its recreational capability (see photos 1 and 2, Chapter Four).

Figure 10. The Sub-foreshore Zone

(e) The Upland Zone

The Upland Zone is defined as the area of undifferentiated steep valley walls, extending inland away from the Foreshore Zone. This zone is characterized by:

1. slopes in excess of fifteen per cent
2. shallow soil depths to bedrock
3. the coarse fragment of the soil greater than fifty per cent.

Using these criteria, the Reservoir Site Region would be investigated and mapped accordingly into the five identifiable landtypes.
Step Three. Establishment of Recreation Management Units (R.M.U.)

The five identifiable landtypes of the reservoir have been determined on the basis of general physical land and water characteristics. Variations within each landtype, depending upon size of the landtype, are naturally to occur, which limit the degree to which recreation can take place, varying amounts of soil wetness in the Foreshore Zone, for example. For this reason, a more detailed analysis of the landtype based along gradients of selected "geophysical values" (also referred to as contributing factors) is undertaken. The result is a subdivision of the landtype into units called Recreation Management Units (R.M.U.). The importance of this step is that the identification of a Recreation Management Unit determines the degree to which it is capable of supporting selected recreational activities. This is because the various gradients of each contributing factor (surface texture, slope, soil wetness, water currents, temperature, etc.) determine the degree of severity for recreational use. These contributing factors of topography, soil characteristics and aquatic conditions are further developed in the final step.

Step Four. Identification of Land-use Capabilities for Recreation Activities

In the identification of land-use capabilities for the Reservoir Site Region, an analysis of both the land and water conditions must be

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1 Recreational activities and their respective mapping codes are listed in Table 2.
<table>
<thead>
<tr>
<th>Reservoir Landtype</th>
<th>Open Water</th>
<th>Littoral</th>
<th>Beach</th>
<th>Foreshore</th>
<th>Upland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recreation Activities</td>
<td>Boating - sailing (S)</td>
<td>Family Bathing (FB)</td>
<td>Sunbathing (S)</td>
<td>Organized camping</td>
<td>Hiking</td>
</tr>
<tr>
<td></td>
<td>- rowing/paddling (C)</td>
<td>Wading (W)</td>
<td>Gathering &amp; Collecting</td>
<td>Picnicking</td>
<td>Scenic Viewing</td>
</tr>
<tr>
<td></td>
<td>- motoring (P)</td>
<td>Swimming (S)</td>
<td>Unorganized games (G)</td>
<td>Hiking</td>
<td>Nature Study</td>
</tr>
<tr>
<td></td>
<td>Water skiing (WS)</td>
<td>Gathering &amp; Collecting (G)</td>
<td>Hiking (H)</td>
<td>Gathering &amp; Collecting</td>
<td>Wildlife</td>
</tr>
<tr>
<td></td>
<td>Nature Study (NS)*</td>
<td>Nature Study</td>
<td>Nature Study</td>
<td>Nature Study</td>
<td>Viewing (W)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Access (A)</td>
<td></td>
<td>Scenic Viewing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scenic Viewing (V)*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* See Explanatory Note (p. 58).
Explanatory Note to Table 2

Many of the terms listed in Table 2 are closely associated with other recreational activities. As a consequence, their definition needs further explanation:

**Nature Study (NS)**

Nature study areas occur where vegetation or wetland wildlife is outstanding in uniqueness and attractiveness. A mature stand of Douglas fir, marshland plants, or upland meadows would all be rated as sustaining high capability for recreational use (1 NS). Similarly, shoreline nesting areas, migration routes, marsh birds and aquatic mammals (C.L.I. Report No. 6) would rate high in capability for a nature study area.

**Scenic Viewing (V)**

Refers to that activity of viewing outstanding portions of the Reservoir Site Region, surrounding terrain, and hydro generating facilities. Viewpoints are not necessarily the highest point of land, although topographic conditions (E) are largely taken into consideration, (steeply sloping gradients and rock outcrops normally offer superior views to undulating slopes facing away from the reservoir, and/or creek gullies).

**Wildlife Viewing (W)**

Refers to the viewing of Upland Ungulates. Capability ratings are on the basis of B.C. Land Inventory Information (Ungulates); existing slopes, depth to bedrock; and surface runoff streams. These restricting factors are collectively grouped into one restricting category: slope (SL). Other activities associated with wildlife viewing included in this grouping are: primitive camping, hiking, and nature study.
made. Capability ratings are therefore determined on the basis of:

1. Geophysical properties
2. Aquatic conditions.

The salient points of these conditions are discussed below.

1. Geophysical Properties

It has previously been submitted (pp. 44-45) that the identification of soil properties enables the land manager to make initial assessments of the land based on its inherent characteristics. This process is done only after the Reservoir Site Region is first classified into its various landtypes. All soils have the potential to be used for some recreational activity. Some offer no limitations for specified recreational uses, while others have moderate to severe limitations (see later definitions) for certain uses. In some cases, local soil conditions may be dangerous if developed for recreational purposes: soils subjected to flash flooding, or landslides, for example. In addition, while the emphasis of soil and topography appears to be directed toward land-based recreation, as developed below, these conditions also affect water-based recreation, particularly in the Littoral Zone.

According to P. Montgomery and F. Edminster (1966), there are at least ten geophysical properties of the land that singly or in combination with others, affect recreational use. Briefly, they are:

(a) Lands subject to flooding. These lands have severe limitations for recreational uses (camp sites, recreational buildings, play areas, etc.). Unless precautions are taken: provision of dikes, levees,
and flood protection structures, etc., these soils should not be used. Instead, they should be left as green belt spaces, hiking, or nature study areas, if flooding is not too frequent.

(b) **Wet Soils (Fibrisols).** These soils are often wet all year, and are characterized by fluctuating water tables at or near the ground surface. For this reason, they are poorly suited to campsites, trails, picnic areas, and playgrounds. Soils that dry out slowly after rains also present problems if intensive recreation use is contemplated.

(c) **Draughty Soils.** Draughty soils, in some cases, can present limitations for recreational use. Grass cover for playing fields, etc., is often difficult to establish and maintain. Without corrective measures, access roads can be dusty, vehicles can be mired down in sandy soils, and sand blowing is common.

(d) **Soil Compaction.** Structure and texture of the soil effect in part the degree to which the soil is "compactible" and can sustain recreational use. Some soils, when wet, will fail to support structures, roads, and trails. An understanding of the shrink-swell potential—how the soil behaves with the addition of water, and the plastic and liquid limits of the soil should also be understood.

(e) **Slope.** Slope affects the use of soils for recreation. Flat to nearly flat (less than 8%), well-drained, permeable, stone-free soils have few to no limitations for use as campsites, playgrounds, picnic and beach areas, and trails, while slopes in excess of 10% have moderate to severe limitations, as well as having higher erosion potential. Slopes in excess of 15% usually suggest shallow soil depths to bedrock and
therefore prohibit septic tank disposal fields for both campsite and second home development. Slopes of less than 10% in the Littoral Zone would also favour recreational use.

(f) Soil Depth. The depth of the soil to bedrock affects many potential recreational uses: shallow soils restrict drainage and are therefore not suitable for septic tank locations. Where bedrock is close to the surface, these soils are difficult to level for campsites, roads, and trails, except at high cost. The establishment of vegetative cover on shallow soils, or on soils over impervious layers, is difficult, and restricts the location for playing fields, and intensive recreation areas.

(g) Soil Texture. The surface texture is an important property of the soil that must be considered in assessing its recreational capability. Soils high in clay content are not suitable for intensive recreational areas in that they become sticky when wet, and are slow to dry after rains. Sandy soils are also undesirable (in the Foreshore Zone), in that when dry, are relatively unstable. A combination between these extremes, the sandy loam, and loam textured soils are the most favourable for recreational use. Texture of the littoral bottom also limits recreational use, with soils high in clay content being least desirable.

(h) Stoniness. The presence of stones, rocks, cobbles, or gravel limits the degree of recreational use on the soil. Those soils that have very stony, stony, rocky, or gravelly soils (for definitions, see U.S.D.A. Soil Survey Manual), have severe to moderate limitations for
use as campsites. In some cases, the removal of stones is possible (based on suitability criteria), although in self-churning soils, this removal process would have to be continued on a regular basis, and at high costs. Angular and sub-angular rocks on the floor of the Littoral Zone also presents hazards to water-based recreation. On steep slopes, the occurrence of gravels and stones are hazardous where paths and foot trails are planned in that these soils are generally unstable when walked on (see Coarse Fragment).

(i) **Coarse Fragment.** The coarse fragment refers to those particle sizes of the soil between 3mm to 10 inches in diameter. The percentage of coarse fragment in the soil determines in large part the compaction of the soil. Soils with a high per cent of coarse fragment generally have little compaction. Also, coarse fragments are less likely to move as a result of running water, and can help thwart the movement of finer particles. However, if the coarse fragment content is excessive, the few finer particles will not bind the coarser fragments together. As a result, the coarse fragment can easily slip if walked on, especially on steep slopes (Morton, Fox, Chilliwack Study, 1975).

(j) **Permeability.** The term 'permeability' refers to the quality of the soil that enables it to transmit air and water. Soil structure and texture are directly related to the permeability of the soil. Soils that are compactible will reduce permeability and remain wetter than those soil that have good air-to-water ratios. Intensive recreational areas require sanitary facilities and in many cases, septic tanks are
the only means of waste disposal. For this reason, it is important that soils are well-drained, permeable, have sufficient depth to bedrock, and are not subject to flooding. Failure to meet these conditions can produce ground water contamination, surface ponding, as well as unpleasant conditions for recreationists.

These ten geophysical characteristics are by no means exhaustive. For the purposes of the framework established in this thesis, they are, however, closely associated with various types of outdoor (land and water-based) recreational activities, and provide a foundation for additional and more intensive analysis. With the aid of soils maps; and knowing the characteristics and behaviour of soils under various conditions, the land manager can begin to develop biogeophysical interpretations for specified recreational uses.

2. Aquatic Conditions

In addition to soils data and topographic conditions, equally important is assessing land-use capability for recreation in recognition of the local aquatic conditions of the reservoir, the operational requirements of the hydro plant and their impact on the reservoir. While the main criteria to be considered are the drawdown feature of the reservoir, the physical properties of water temperature, turbidity, wind and wave action, etc., must also be considered and the degree to which they affect recreational use of the water.

The drawdown of the reservoir is determined mainly by energy demands, and the installed capacity of the plant to release water; the
installed capacity being determined chiefly by the availability of water (inflow into the reservoir) and the reservoir's capable storage. Evaporation and seepage losses only somewhat affect reservoir levels.

Both large storage and coastal reservoirs follow drawdown patterns (see p. 33). On many of the coastal reservoirs, a distinctive situation prevails. Generation from these reservoirs often operates in a peaking mode, filling the electricity demand peaks during the day (see Figure 11). This characteristic is true of both storage and run-of-the river reservoirs of the Coastal System in summer. Depending upon the

![Figure 11. Daily Demand Curve of an Electrical Utility, with mixed generation available.](image-url)
the generating plants idling during the night to allow for surcharging for the following day. Hayward Lake, a run-of-the-river reservoir is a good example of this phenomenon. While operating under these normal conditions, this can also increase the surface water currents and present increased hazards to on-water activities. Reservoirs also spill excess water during high run-off periods, thereby alluviating flooding by having first utilized available storage. Ideally, the spill eventually passed is less than the peak inflow, giving a secondary flood control benefit. This action increases the normal C.F.S. of the water along the lake and can further result in increased currents.

In addition to the geophysical and aquatic conditions, there are also certain biophysical requirements that must be considered in determining land capabilities for recreational use. These are:

(a) **Vegetative and tree cover** must be examined and the degree to which they provide wind and sun shelter for campground and picnic facilities.

(b) **The orientation of the land** with respect to the reservoir, and the degree of slope must also be considered for viewing of the reservoir site region, surrounding terrain, and hydro generating facilities.

(c) **Access to the water** for power boats, sailboats, and canoes should include analysis of beach and foreshore slopes, subsurface slopes and textures in the Littoral Zone, water currents where prevalent, in addition to the provision of parking facilities for automobiles (U.S. Bureau of Outdoor Recreation) in the Foreshore Zone.
(d) **Beach exposures** to sun and wind and **biological productivity** in the Littoral Zone, significantly affect the degree of recreational use and capability for specified recreation activities.

While an empirical rating cannot be assigned to each of these contributing factors, their relative importance to recreational requirements is paramount and should be based on the prevalence of the existing condition. For example, a southwest exposure during the summer is more desirable than a northern exposure for beach and foreshore recreational activities. Similarly, a dense tree stand located in an area exposed to high winds would be more desirable for recreational use (e.g., campgrounds) than an area with sparse vegetation cover and subjected to similar wind conditions.

**DEGREE OF LIMITATIONS FOR RECREATIONAL USE**

In this study, the biogeophysical conditions determine the degree of limitation: None to Slight (Class 1); Moderate (Class 2); and Severe (Class 3) for specified recreational uses within each management unit. These three classes are described as follows:

1. **None to Slight Limitation.** Refers to the soil, the local aquatic conditions, and operations requirements being relatively free of limitations that affect the intended use, or that the limitations are easy to overcome. None to slight limitations suggest that specified recreational activities can also be sustained with minimum effects to the environment.
2. **Moderate Limitations.** Moderate limitations for land-based recreation result from the effects of slope, wetness, soil depth, texture, exposure, vegetative cover, etc. For water-based recreation, slope, texture, stones, etc., can restrict littoral activities, in addition to water turbidity, temperature, and hazardous water conditions. Normally, the limitations can be overcome with correct planning, proper land management, and careful design. Areas of moderate limitation may imply financial management costs to rectify local conditions, and should therefore include suitability and feasibility assessment.

3. **Severe Limitations.** Severe limitations represent conditions that are unsuitable for public use. On land, these conditions result from excessive slopes, high water tables, flooding, stoniness, unfavourable soil conditions (texture) etc. Severe limitations in the Littoral and Open Water Zones result from hazardous lake bottoms, surface currents, high water turbidity, advanced stages of eutrophication, cold water temperatures, etc. Due to the severity of these conditions, these limitations prohibit most recreational use of the land and water, unless major reclamation work is undertaken.

The following tables are used to determine the subdivision of the landtype into Recreational Management Units and the degree to which the biogeophysical limitations affect specified recreational uses. The degree of limitation (Classes 1-3) is established by the prominence of one or more factors. Due to the complex interaction and cause-effect relationships that occur on the land and water, the occurrence of one contributing factor often leads to other identifiable factors within
### TABLE 3

Criteria Considered in Rating Capability for the Open Water Zone

<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>Increasing severity of limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>None to Slight</td>
<td>Severe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Access (A)</th>
<th>1 or more public access points per 300 lake acres (Jaakson 1970)</th>
<th>1 public access per 1000 lake acres</th>
<th>No access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed (W)</td>
<td>less than 10 mph</td>
<td>10-15 mph</td>
<td>greater than 15 mph</td>
</tr>
<tr>
<td>Lake Morphology (H)</td>
<td>Large lake size without obstruction, (stumps, reeds, etc.)</td>
<td>Shallow water depths</td>
<td>Shoreline reeds and sedges</td>
</tr>
<tr>
<td></td>
<td>Deep open water</td>
<td>Narrow bay and inlet</td>
<td>Submerged stumps</td>
</tr>
<tr>
<td></td>
<td>Large, well-rounded bays</td>
<td></td>
<td>Bottom debris</td>
</tr>
<tr>
<td></td>
<td>High water quality</td>
<td></td>
<td>Steep shoreline cliffs</td>
</tr>
<tr>
<td></td>
<td>Lack of bottom debris</td>
<td></td>
<td>Advanced stages of eutrophication</td>
</tr>
<tr>
<td></td>
<td>Diversity of shoreline landforms</td>
<td></td>
<td>Water pollution</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High water turbidity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size of Zone*</th>
<th>&gt;1000 acres</th>
<th>500-1000</th>
<th>&lt;500 acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boating Density (existing) (D) Open Water surface (Jaakson, 1970)</td>
<td>Less than 1 boat per acre of</td>
<td>5-10 boats per acre</td>
<td>Greater than 10 boats per acre</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Special Hazards (H)</th>
<th>Water currents, daily water fluctuations</th>
<th>(Severity of limitation depends on prevalence of condition)</th>
</tr>
</thead>
</table>

Note: Lake morphology affects the degree to which different boating activities can coexist within the same zone. Small, narrow reservoirs, for example, preclude motor boats, but are suitable for canoes and sailboats (see discussion Chapter Five, 'Water-Zoning').

* Refers to power boats only.
TABLE 4
Criteria Considered in Rating Capability for the Littoral Zone

<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>None to Slight</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Quality (Q)</strong></td>
<td>Clear water</td>
<td>Balanced nutrient levels</td>
<td>Suspended solids Water turbidity Advanced eutrophication High nutrient levels</td>
</tr>
<tr>
<td>Temperature (mean summer months) ( (T_p) )</td>
<td>greater than 65 F</td>
<td>55-65 F</td>
<td>Less than 55 F</td>
</tr>
<tr>
<td>Subsurface Texture (T)</td>
<td>Sands, small pebbles, and stones</td>
<td>subangular stones, and rocks</td>
<td>submerged logs and stumps, angular rocks</td>
</tr>
<tr>
<td>Slope (SL)</td>
<td>Less than 5%</td>
<td>5-10%</td>
<td>Greater than 10%</td>
</tr>
<tr>
<td>Width of Littoral Zone (W)</td>
<td>Greater than 100 feet</td>
<td>50-100 feet</td>
<td>Less than 50 feet</td>
</tr>
<tr>
<td>Special Hazards (H)</td>
<td>Water currents, daily water fluctuations (Severity of limitation depends on prevalence of conditions)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The presence of standing trees in the Littoral Zone does not affect the capability rating of the zone. However, feasibility and suitability for recreational use will be respectively affected where standing trees are prevalent since their occurrence implies management decisions and financial costs for their removal.
### TABLE 5
Criteria Considered in Rating Capability for the Beach Zone

<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>increasing severity of limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Texture (T)</td>
<td>None to Slight</td>
</tr>
<tr>
<td>Sand</td>
<td>Gravel</td>
</tr>
<tr>
<td>Sand-gravel</td>
<td>Sand-boulders</td>
</tr>
<tr>
<td>Sand-stones</td>
<td>Gravel-stones</td>
</tr>
<tr>
<td>Gravel-sand</td>
<td>Gravel-boulders</td>
</tr>
<tr>
<td></td>
<td>Till and Shale</td>
</tr>
<tr>
<td></td>
<td>Stones-sand</td>
</tr>
<tr>
<td></td>
<td>Stones</td>
</tr>
<tr>
<td></td>
<td>Stones-boulders</td>
</tr>
<tr>
<td>Miscellaneous (M)</td>
<td>Beach Exposed (Limitation depends on prevalence of condition).</td>
</tr>
<tr>
<td>Width (W)</td>
<td>Greater than 100 feet</td>
</tr>
<tr>
<td>Slope (SL)</td>
<td>2-8%</td>
</tr>
<tr>
<td></td>
<td>0-15%</td>
</tr>
<tr>
<td>Special Hazards (H)</td>
<td>Dangerous slopes, currents or undertows (Severity of limitation depends on prevalence of condition)</td>
</tr>
<tr>
<td>Exposure (E)</td>
<td>&quot;</td>
</tr>
<tr>
<td>Contributing Factors</td>
<td>Increasing severity of limitation</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Wetness (D)</td>
<td>Well to moderately well drained soils with no ponding and with water table below 3 feet</td>
</tr>
<tr>
<td>(See Drainage Classes Appendix 2)</td>
<td></td>
</tr>
<tr>
<td>Flooding (F)</td>
<td>None</td>
</tr>
<tr>
<td>Exposure (E)</td>
<td>Depends upon prevalence of condition</td>
</tr>
<tr>
<td>Permeability (P)</td>
<td>Very rapid to moderate</td>
</tr>
<tr>
<td>Slope (SL)</td>
<td>Less than 9%</td>
</tr>
<tr>
<td>Surface soil texture (T)</td>
<td>sl, fsl, vfs1, 1, and 1s with textural b horizon, not subject to blowing</td>
</tr>
<tr>
<td>Coarse Fragment (CF)</td>
<td>Less than 15%</td>
</tr>
<tr>
<td>Stoniness (S) or rockiness</td>
<td>None</td>
</tr>
<tr>
<td>Depth to Bedrock (B)</td>
<td>More than 6 feet</td>
</tr>
<tr>
<td>Vegetative Cover (V)</td>
<td>Severity of limitation depends upon prevalence of condition</td>
</tr>
</tbody>
</table>

1 Based on soil limitations during use season.
2 In low rainfall areas soils may be rated one class better.
3 For definitions see USDA Soil Survey Manual.
<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>None to Slight</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (SL)</td>
<td>Less than 8%</td>
<td>8-15%</td>
<td>Greater than 15%</td>
</tr>
<tr>
<td>Flooding (F)</td>
<td>None</td>
<td>May flood for short periods, but not during season of use</td>
<td>Flooding, may flood in season of use</td>
</tr>
<tr>
<td>Surface soil texture (T)</td>
<td>gravels, loams</td>
<td>clay loams, sandy loams</td>
<td>clays, loamy sands, sands, silt loams, silts</td>
</tr>
<tr>
<td>Coarse Fragment (F)</td>
<td>15%</td>
<td>15-50%</td>
<td>50% +</td>
</tr>
<tr>
<td>Wetness (D)</td>
<td>Well to moderately well drained, with no ponding</td>
<td>Well drained, moderately well drained, occasional ponding</td>
<td>Poorly, and very poorly drained, somewhat poorly drained, subject to ponding, wet at least 4 weeks during season of use</td>
</tr>
<tr>
<td>Compaction ability (C)</td>
<td>gravels, sands</td>
<td>loamy sands, sandy loams (when not wet)</td>
<td>clays (when silts, loams, sandy loams not wet), silts, loams, silty loams, clay loams</td>
</tr>
<tr>
<td>Exposure</td>
<td>Severity of limitation depends upon prevalence of condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation Cover</td>
<td>&quot;</td>
<td>&quot;</td>
<td></td>
</tr>
</tbody>
</table>

Source: (Montgomery, Edminster, 1966).
### TABLE 8
Criteria Considered in Rating Capability for the Paths and Trails

<table>
<thead>
<tr>
<th>Contributing Factors</th>
<th>None to Slight</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetness(^2)</td>
<td>Well and moderately well drained soils with seasonal water table below 3 feet</td>
<td>Well and moderately well drained soils subject to seepage or ponding and somewhat poorly drained soils. Seasonal water table 1-3 feet</td>
<td>Poorly drained and very poorly drained soils</td>
</tr>
<tr>
<td>Flooding(^2)</td>
<td>Not subject to flooding during season of use</td>
<td>Subject to occasional flooding. May flood 1-2 times during season of use</td>
<td>Frequent flooding during season of use</td>
</tr>
<tr>
<td>Slope(^3)</td>
<td>Less than 30%</td>
<td>30-70%</td>
<td>70% +</td>
</tr>
<tr>
<td>Surface soil texture</td>
<td>s1, fsl, vfps1, l</td>
<td>s1cl, sicl, scl, cl, sc, ls.</td>
<td>sic, c, sand and soil subject to severe blowing Organic soils</td>
</tr>
<tr>
<td>Coarse fragment</td>
<td>10-15%</td>
<td>0-10%; 15-80%</td>
<td>Greater than 80%</td>
</tr>
<tr>
<td>Stoniness or rockiness</td>
<td>Classes 0,1,2</td>
<td>Class 3</td>
<td>Classes 4, 5</td>
</tr>
</tbody>
</table>

1. The patterns of these trails should fit the landform, i.e., different design on steep slopes, and on different soils may diminish the impacts on the environment.
2. Season of use should be considered in evaluating these factors.
3. Soil erodibility is an important item to evaluate in rating this condition.

Source: (Montgomery, Edminster, 1966).
the same degree of limitation. As a consequence, lower case symbols (the limiting factor) in the classification for an R.M.U. are often related; i.e., soil textural classes to drainage classes.

The contributing factors that are considered do not necessarily reflect the conditions for all recreational uses. For this reason, a maximum of three selected recreational activities are rated according to their capability for each unit (see Figure 12).

LIMITATIONS OF THE IDENTIFICATION FRAMEWORK

The identification framework established in this chapter does not purport to be complete, but rather serves the land management planner as a tool to identify areas of conflict between public recreational use and local physiographic conditions. It does not meet the general problem of competing uses for the same recreational space, particularly on the Open Water Zone, where canoeists and water skiers conflict. For this reason, an examination of possible water zoning in terms of space (area) or time (hours, days) or combination of these is necessary, and cannot be solved solely on the basis of capability. Size and shape of the reservoir does, however, play an important role in effecting the degree to which these activities can be accommodated (see later discussion, Chapter Five).

Secondly, the classification and capability rating system is based solely on the physiographic components of landform and soil conditions. Little consideration is given to vegetation: the types and amounts of vegetation for shade, nature study, and aesthetics. This part
Figure 12. Recreation Capabilities: The Foreshore Zone

Discussion of Capability Ratings for Figure 12

R.M.U. 1 rated as: \[3C\, 3P\, 2NS\, \text{t\ t\ sl}\]

In this management unit, the capability rating for the selected recreational activities are severe. Campground facilities are severely restricted due to surface textural conditions (t) (most probably silt loams and very fine silt loams), with picnic facilities also being severely restricted due to the same limiting factor. The management unit does have interesting nature study conditions (NS), but is somewhat restricted due to slope conditions in the area making access slightly difficult.

R.M.U. 2 rated as: \[2C\, 1V\, 2T\, \text{sl\ t}\]

This management unit has moderate to high capability for recreation. Slope conditions (sl) (10-15%) do restrict campground facilities moderately, with surface textural conditions (t) also affecting trails and footpaths through the unit. Scenic viewing (IV) of the Reservoir Site Region and/or the hydro generating facilities is rated high.

R.M.U. 3 rated as: \[1C\, 1P\, 1T\]

This management unit presents unique opportunities for recreational uses (Camping (C), Picnicking (P), and Trails (T)). There are no restricting factors for the three recreational uses in the management unit.
is primarily considered in the overall description of the area. Areas of sparse to no vegetation cover would naturally rank lower than areas with vegetative cover. This part of the assessment is more subjective rather than empirical in form.

Thirdly, the classification system should not be confused with "best use" for the term "best" implies improvements to the land—its suitability and feasibility. This classification system identifies recreational potential based on the natural conditions of the land, with little or no improvements being necessary in order to develop this potential. For this reason, the technique should only be used as the first stage in developing a comprehensive land management plan for the reservoir site.

Finally, the limiting factors that are examined are done purely on the availability of existing data. Field sampling to verify the data is done where possible in the case study. Because only selected criteria are examined, the full range of limiting factors are not covered. This exclusion of certain components naturally leads to inherent weaknesses in the technique and validity of the results.
CHAPTER FOUR

RECREATIONAL LAND-USE CAPABILITIES OF THE
HAYWARD LAKE RESERVOIR SITE REGION

In this chapter, the recreation identification framework is applied to a hydro generating reservoir; Hayward Lake, British Columbia. The purpose of the case study serves two useful functions. First, it tests the relevance and applicability of the developed framework. Secondly, it provides the necessary background information for comprehensive land-evaluation of the Reservoir Site Region.

This chapter covers three main topics: the physical characteristics of the study area; an outline of the procedure followed in the classification technique; and a discussion of the capability ratings.

PHYSICAL CHARACTERISTICS OF THE RESERVOIR SITE REGION

Definition of the Site Region

This case study examines Hayward Lake, a reservoir formed by the construction of Ruskin Dam on the Stave River. The project is located at the southern boundary of the British Columbia Coastal Mountains and their confluence with the Fraser River Lowlands, approximately forty miles east of Vancouver (see Study Area, Map 1).

As previously defined (p. 6) the extent of the Reservoir Site Region includes the surface area of the reservoir and that land area
MAP 1. LOCATION OF STUDY AREA
away from the water's edge to either, (1) the surrounding height of land, or (2) one mile from the reservoir.

In this study, the upstream extent of the Site Region is determined by the Stave Falls and Blind Slough Dams. The tail waters of these two dams enter Hayward Lake both by means of a river channel approximately one-half mile long (see Site Region and Map 2). The latitudinal upstream boundary is determined by a line drawn parallel to the two dams for a distance of one mile. The longitudinal boundaries of the reservoir are drawn one mile equidistant from the reservoir or to the surrounding height of land. The extent of the Site Region downstream is determined by the Ruskin Dam. The northern latitudinal boundary follows a ridge from the height of land and is adjacent to a steeply gullied creek that flows into the reservoir. The southern latitudinal boundary is located along the "break of slope" on the west side of Harsine Ridge to one mile from the reservoir.

Geography and Hydrology

Hayward Lake Reservoir occupies the old river channel of the Stave River. Operating at a level of 211 feet above sea level (datum based on a lower low tide 70.22 feet higher than true mean sea level), the reservoir covers approximately $31.51 \times 10^6$ square feet (700 acres) with a total length of 3.5 miles and an average width of 0.3 miles.

The land rises steeply from the reservoir to the east to a maximum elevation of 1750 feet A.S.L. and less steeply to the west to a maximum elevation 1150 feet A.S.L. (see Photos 1 and 2).
Photo 1. N.E. Area of Site Region. Note steep Subforeshore and Upland Zones.

Photo 2. N.W. Area of Site Region characterized by steep Subforeshore. Foreshore not shown in photo.
The area has been subject to heavy glaciation and was covered by a continental ice sheet 15,000 years ago (I.P.E.C., 1969). Evidence of this is found by the glacial and post-glacial deposits of up to several hundred feet thick along the valley bottoms. In the upland areas, the overburden consists of a relatively thin cover of glacial drift. The surrounding mountains are also typically rounded in form and characteristic of glaciation.

The region is underlain by granitic rocks of the Mesozoic Age. Diorite is the dominant rock type. While the region is covered by a mantle of overburden, outcrops around the Ruskin and Stave Falls Dams are evident. Slopes here are in excess of 70%.

The surficial material in the region consists of: gravel and sand deposits (outwash deposited by the glaciers and Stave River); silts and clays (usually glaciomarine); and tills (unsorted materials deposited by glaciers).

Hydrological conditions at Hayward Lake are governed primarily by water releases at Stave Lake (catchment area of approximately 450 square miles). This can result in a maximum inflow of approximately 120,000 cubic feet per second (cfs) into Hayward during peak run-off periods (based on a 100 year return flood). The average annual precipitation at Stave Falls is 80 inches, with the peak period occurring between November to January. During these months, monthly totals average 9-11 inches (I.P.E.C., 1969).

Since much of the precipitation in the catchment area falls in the form of snow, the greatest volume of run-off occurs in the spring
months, with the flood hydrograph peaking in June. A second inflow period occurs in the autumn months (October through December) with the run-off principally being derived from rainfall and aggravated by (potential) snowmelt. Due to the geophysical characteristics of the drainage basin (see p. 28) the run-off period in the catchment area is approximately 48 hours and can cause rapid rises in Stave Lake. This can possibly lead to a spill through Hayward Lake (see Figure 13).

![Figure 13. Run-off Characteristics into Stave Lake](image)

**Climate and Vegetation**

The climate of the Hayward Lake Site Region is classed as inshore Maritime with warm wet winters and dry summers. The temperature at Stave Falls and Mission record a winter mean of 2.2°C and a summer
mean of 17.7 C with temperatures in August reaching 29 C. Krajina's classification (*Biogeoclimatic Zones of British Columbia*) defines the area as the Coastal Western Hemlock, although the Site Region is located on the interface of this class and the Coastal Fir region of the Fraser Valley. For this reason, the forest canopy is visibly mixed and may be referred to as a Temperate Marine Rain Coniferous Forest (Krajina, 1965).

Tree species consist of: Douglas Fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), Western red cedar (*Thuja plicata*), Broadleaf maple (*Acer macrophyllum*), and Alder (*Alnus spp.*). The classification system of the Society of American Foresters would rate the area as Type 230: Douglas Fir-Western Hemlock, where Douglas Fir often predominates but does not make up 80% of the dominant canopy, and where conversely, Western Hemlock can also be present in significant amounts and may predominate up to 80%. This forest type is usually in the mid-phase in the natural succession from the subclimas Douglas Fir to the climax Hemlock. Evidence of this succession was found in the various field trips to the Reservoir Site Region (see Photos 1 (p. 81) and 3).

**Fish and Wildlife**

Fish species in Hayward Reservoir are not prolific for two reasons: (1) due to the lack of littoral vegetation, there is little feeding stock around the shoreline, and (2) the Ruskin Dam has impeded fish from passing into the reservoir. The lake however does support
small populations of Rainbow and Cutthroat Trout and Kokanee. The sloughs below the Ruskin Dam are used by Chum salmon, and to a lesser degree by Pink salmon. Although fluctuations in water level and rapid surges in the flow of the tail race have serious effects on the juvenile fish and eggs, this appears to be the most favourable area for spawning.

The only ungulate present in the study area is the black-tailed deer. According to the British Columbia Land Inventory (B.C.L.I.) for ungulates the area is classed as: $4^R_d$, where Class 4 is defined as:

Lands in this class have moderately severe limitations to the production of ungulates. The area so classed will sustain
a population of (or equivalent to) 10-20 white-tailed deer per square mile per year (B.C.L.I. Ungulates, 1973).

Sub-class "R" indicates:

. . . limitations due to depth to bedrock or other impervious layers.

Map symbol "d" indicates:

. . . the presence of deer (Odocoileus hemionus and Odocoileus virginianus).

Waterfowl on the reservoir are not abundant due to the lack of aquatic vegetation and shoreline nesting areas. The B.C.L.I. for Wildlife classes this area as: $6^J_Z$

Class $6$ lands have severe limitations to the production of waterfowl. Capability on these lands is very low. Limitations are easily identified. They may include aridity, salinity, very flat topography, steep-sided lakes, extremely porous soils, and soils containing few available minerals.

The capability subclasses "J" and "Z" refer to a reduced marsh edge and deep off-shore waters which limit the development of optimum waterfowl habitats.

**Existing Land Use and Access**

The Hayward Reservoir Site Region falls within the Municipal District of Mission and is subject to zoning regulations. Five zones within the study area were identified:

RSV-1 Limited Use Reserve Area - 80 acres minimum lot,
RSV-2 Institutional Reserve Area - 80 acres minimum lot,
RRL-1 Acreage Rural Area - 5 acres minimum lot,
RRL-2 Upland Rural Area - 10 acres minimum lot,
RRL-3 Lowland Rural Area - 20 acres minimum lot.
Residential development in the study area is evident in the northern and southern parts of the Site Region, along Dewdney Trunk Road, Keystone Road, and Shaw Roads. Minimum size lots are 5 acres.

Access to the Site Region is provided by three hard surface, all weather roads. In addition, a private road (closed to the public) runs the entire length of the reservoir along the west shoreline (see Map 3 and 4 and Photo 4).

Photo 4. Private access road along west shoreline. Note reservoir at left of photo.

The Ruskin Power Development

The story of Ruskin is one of conquest, of bending the rushing torrent to the will of man, of removing nature's barriers and replacing man's. Could the stones and ripples of the river but speak, they would tell a tale of speed, how in twenty months the swirling eddies and rapids gave way to a placid lake, how
MAP 3. EXISTING ZONING
MAP 4.
EXISTING LAND USE
men suddenly came and as suddenly departed leaving a new landscape and a new structure containing its humming machinery driven by the force of pent-up water. (B.C. Power Corporation, 1930).

This excerpt dramatically emphasises the romanticism and engineering determinism that was generated by the rapidly growing hydro projects that began in British Columbia (circa, 1897). The projects developed were impressive monuments to an era that stressed expedient project completion and singularity in technological function. The Ruskin Power Development, designed to produce power for the growing Vancouver region, exhibited a similar quality of surgence and was accomplished without interference from costly union and management controls.

Completed in less than two years, the project was initiated in December of 1928 and was conceived as the third and final step in the use of water from the Stave River system. Prior to development, the Stave River meandered through the terraced valley below Stave Falls. At the Ruskin Dam site, the river had cut its way deeply through a rock barrier that had once blocked its course (see Photos 5, 6, 7 and 8). Continued erosion formed a gorge some 160 feet deep and steep enough to develop approximately 130 feet of head. The Ruskin Dam, constructed of dimensions 195 feet high and 370 feet long captures the total available head of water before it debouches into the floodplain of the Fraser River.

At full capacity, the Ruskin Plant generates 105,600 kilowatts of power using 12,000 cubic feet of water per second. Its operating schedule may be defined as a peaking system, which involves full output
THEN and NOW

The two views on this page were taken from the same location, the upper showing the canyon before the development was started and the lower the lake formed by the dam.
CONTRASTS

These two pictures, taken from practically the same spot, show the change that has taken place in less than two years. Above is the mouth of the canyon across which the dam, seen in the lower picture, was built.

Source: British Columbia Power Corporation, Ruskin, 1930.
at the plant only during peak demands, normally a few hours in the morning and evening. Because the generating capacity of the Ruskin plant is greater than at Stave Falls at full operating conditions, the reservoir is drawn down an average of 2-3 feet twice daily (assuming no spill conditions), and allowed to surcharge fully overnight for use the following day. In addition to 12,000 cfs used for generation, an additional 130,000 cfs can be spilled over the dam crest when flood conditions prevail (see Figure 14).

![Figure 14. Reservoir Levels at Hayward Lake (daily).](image)

Note: These levels represent year round conditions since the operating policy is to maintain Hayward Lake at maximum level for maximum operating efficiency.
LANDTYPES AT HAYWARD RESERVOIR: THE MAPPING PROCEDURE

As previously defined (p. 51), six landtypes can be identified within a Reservoir Site Region. The field research at Hayward Reservoir confirmed this definition, with some landtypes being better defined than others. This can be explained in part due to the level of shoreline and reservoir stabilization, and the physical morphology of the area. See later explanation.

The six landtypes of the reservoir were divided into Water-based (Open Water and Littoral Zones) and Land-based (Beach, Subforeshore and Upland Zones) categories.

Water-based Landtypes

(a) The Littoral Zone

The Littoral Zone was established by field survey of the water's edge and a thorough examination of the entire shoreline using aerial photographs. Except in isolated cases, it was found that this zone extended to a maximum of 10 feet from the shoreline (at high and low water levels) with average slopes in excess of 20%. Surface textures ranged from gravelly sands to stones mixed with boulders. Aquatic vegetation was not evident.

Due to the scale of mapping employed in the classification technique, the "lateral extent" (distance from shoreline to the five foot contour depth) of the Littoral Zone could not be mapped in its entirety. Four areas within the Littoral Zone of significant size
were identified in the northern section of the reservoir. Their recreation capabilities are discussed on page 108 of this chapter.

(b) The Open Water Zone

The Open Water Zone is identified as that surface area of the reservoir excluding the Littoral Zone. At Hayward Reservoir, the Open Water Zone included practically the total surface of the reservoir as the Littoral Zone occupied only a small ribbon along the shoreline. The shoreline of the reservoir could be rated "irregular" with a moderate number of irregularities per linear mile of shoreline (Adams, Zoltai, 1969), and a few prominent inlets and peninsulas (see Map 5).

Land-based Landtypes

(a) The Beach Zone.

Beach Zones at the site were not significant and have been slow to develop for two reasons: (1) the lack of sediment and suspended load in the discharges from the Stave Falls Dam has reduced the likelihood of deposition and shoreline beach formation and (2) beach formation from bank erosion has been retarded by the heavy vegetation cover that acts as a soil "stabilizer." This cover extends up to the water's edge in most instances. The steep shoreline counteracts this semi-stable condition, with the result being that a ribbon of small boulders and stones has accumulated at the land/water interface which can be seen at both high and low water levels (see Photos 9 & 10 and Map 5).
Photos 9 and 10. Typical examples of small boulders and stone accumulations along the reservoir shoreline.
(b) The Subforeshore Zone

The Subforeshore Zone is defined as that land surface away from the water's edge and immediately bordering the foreshore where slopes are in excess of 15%. The subforeshore is generally an embankment and part of the original terraced valley (Photo 11). Depending upon the surrounding terrain, a series of subforeshores can exist. In the case study, this zone occupied a substantial portion of the shoreline in the central and southern portions of the reservoir region (see Map 6).
METHOD FOR ESTABLISHING THE SUBFORESHORE, 
FORESHORE AND UPLAND ZONES

Because the subforeshore foreshore and upland zones are determined chiefly on slope criteria, slope gradients had to be determined for the Site Region. Four (4) steps were involved in establishing their boundaries. Briefly, they are as follows:

1. A one-half inch grid was drawn over a map of the study area. A map scale of 1:12,500 with a contour interval of 25 feet was used. This produced a matrix comprising approximately 1700 units.

2. The average slope for each unit was computed using an averaging formula where:
   \[ \text{Slope (in per cent)} = \frac{\text{Difference (Max-min Contour + 1 C.I.)}}{\text{Radius}} \]

3. Using an isarythmic mapping technique, a series of eight (8) slope gradient were drawn based on the following class intervals:
   
   1. less than 5%  
   2. 5-9%  
   3. 10-14%  
   4. 15-19%  
   5. 20-29%  
   6. 30-49%  
   7. 50-69%  
   8. 70% +

4. Finally, these slope intervals, along with spot checks in the field were used to establish the boundaries of the three zones.
(c) The Foreshore Zone

Four distinct areas of foreshore were identified at the reservoir site, three of which were separated from the reservoir by a sub-foreshore zone. The foreshore zones were characterized primarily by land areas having slopes 15% or less. In the mapping technique employed, the foreshore zone often resulted in the inclusion of some areas in excess of this slope. These anomalies were the result of land promontories and creek gullies and comprised a small percentage of the total foreshore zone (see Figure 15).

Figure 15. The Foreshore Zone
(d) The Upland Zone

The Upland Zone consisted of that land away from the reservoir that was characterized by slopes in excess of 15%. Within the site region the upland zone was only well defined at two locations: the northeastern sector where the zone began abruptly at the water's edge (slopes 50-70%); and the southwestern sector which also displayed similar conditions of slope and topography (see Map 6).

Having identified the six landtypes of the reservoir, the final step involves analysis of the biogeophysical conditions within each landtype. The resulting subdivisions are referred to as "Recreation Management Units" (see p. 56). On the basis of selected attribute recreational requirements, each Recreation Management Unit is rated according to its ability to support three different activities. The capability ratings are discussed below.

DISCUSSION OF CAPABILITY RATINGS

The capability ratings established for each Recreation Management Unit are based on the biogeophysical characteristics of the Hayward Lake Reservoir Site Region. They are not intended to recommend uses within each unit since they provide only the inherent potential of the area to support various types of recreational use. Capability ratings do, however, provide answers to at least two questions (Spencer, 1972). (1) What are the biogeophysical conditions that limit use of the particular site, and (2) what level of resource-use can the area be expected to achieve given certain stated constraints.
Based on these findings, a Land Management Policy Recommendation is given for each landtype of the reservoir site region.

Water-based Landtypes

(a) The Open Water Zone

The Open Water Zone presents many recreational opportunities for on-water activities. The majority of the southern portion of the reservoir is rated Class 1 for canoe and sailboats with moderate restrictions for power boats due to lake size limitations. The small inlets (Harsine Creek) provide good opportunities for canoeing, fishing and nature study while sailing and power boating are restricted. Access to the reservoir is rated Class 1 and 2 in the northern section, with Class 3 ratings for the southern portion. The area immediately adjacent to the Ruskin Dam is also rated Class 3 for all on-water activities due to surface and sub-surface currents caused by the power generating facilities.

In the northern portion of the Open Water Zone, conditions are influenced directly by releases from the Blind Slough and Stave Falls Dam. The boundaries of these zones (see Map 7) were determined on the basis of site inspection at a time when 48,500 cubic feet of water per second (cfs) were being released from the combined operations of both dams. An examination of spill records to 1964 showed that the majority

1 Water skiing in this zone would be rated Class 3 due to its size and dimensions (Jaakson, 1972). This is even more critical in the northern portion of the reservoir where the Open Water Zone is less than one-third of a mile wide.
MAP 7.

RECREATION CAPABILITIES
OPEN WATER, BEACH
& LITTORAL ZONES

SCALE
0
miles
of releases (for spilling) occurred during October through January. Maximum spills of 4,850 cfs were recorded for June of 1964.

Under normal power generating conditions (October to June), the Stave Falls Plant is run at full capacity (8,000 cfs) 24 hours a day. Channel flows below the dam are therefore kept relatively constant. During the months of June, July, and August, with lower power demands, the average flow is decreased to 2,000-3,000 cfs. During this period maximum generation occurs only when the rest of the power grid requires it, or when Stave Lake is "topped off" to maximum elevation. This latter condition results when the last of the snowpack is released, and Stave Lake reaches maximum elevation. In some instances, a check spill at the Blind Slough Dam is required, usually less than 4,000 cfs.

According to Mr. B. Creer, a Director of Whitewater Canoe Sports in British Columbia, the channel below the Stave Falls Dam, under normal operating conditions (steady flow) is rated Grade 1-2. The International River Classification describes these Grades as follows:

**Grade 1** Suitable for novices in closed canoes, kayaks, and Open Canadians.

Easy. Waves small and regular; passages clear; occasional sand banks and artificial difficulties like bridge piers.

**Grade 2** Suitable for intermediate paddlers in closed canoes, kayaks and Open Canadians.

Quite easy. Rapids of medium difficulty; passages clear and wide. Occasional boulders in streams. Open canoes may ship water in places.

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2 Short periods of 8,000 cfs (approx. 2 hrs.) in the early morning and evening periods.
The Open Water Zone of the Reservoir Site Region has been analyzed with recreation capability ratings being assigned to various portions of the zone. These ratings have been determined by the availability of existing hydrological data, field research, and in conjunction with the information presented in Table 3, (p. 68). It should be pointed out that Policy Recommendations for each landtype are based solely on capability analysis. The recommendations do not consider demand and cost factors, implementation and management responsibilities, and trade-offs between energy-use of the reservoir and recreation opportunities. These conditions ultimately must be included in the final analysis of the Hayward Lake Site Region.

LAND MANAGEMENT POLICY RECOMMENDATION FOR THE OPEN WATER ZONE

1. Thorough examination of hydrological conditions should be made and a team of hydrologists and recreation experts should examine the currents in the Open Water Zone during the recreation season.

2. Canoeing of the channel below the Stave Falls Dam should only be permitted in conformity with local operating conditions at the plant.

3. Due to the small and narrow dimensions of the reservoir in the northern portion it is recommended that power boats be eliminated and that power boats in the southern portion of the reservoir be kept to a maximum of five horsepower.
Photos 12 and 13. Examples of the Beach Zone along the N.W. Shoreline. Restricting factors are width and exposure. Note Wet Beach area.

Photo 14. Wet Beach, bordered by grass covered alluvium sands to left of photo.

Photo 15. Potential Class 1 Beach, presently covered by scrubs and grasses.
4. An extensive stump clearing program should be carried out to facilitate on-water activities. This should include the removal of all stumps protruding above 120 feet ASL. At present surface and sub-surface stumps present a serious hazard to boating on the lake.

(b) The Littoral Zone

Development of the Littoral Zone was not significant along the reservoir shoreline. For this reason, the greatest percentage of the zone was rated $3B\ 3W\ 3A$ due to the following restricting factors: (s1) subsurface slopes in excess of 20%; (t) bottom textures ranging from sands and gravels, to subangular stones, rocks, and decayed logs; (A) and restricted access from the beach and foreshore.

As shown by Map 7 (p. 104) significant littoral areas are confined to the northern portion of the reservoir. It is in these regions that hazardous water conditions are more prevalent. Surface currents generated by releases from the Blind Slough Dam and to a lesser extent from Stave Falls Dam, constitute the major contributing factor to surface currents. The capability ratings for these zones are based on the maximum possible releases during the summer months and their degree of influence on water currents. Consequently, while a zone receives a Class 3 rating due to hazardous water conditions (h), this does not imply continual hazardous conditions since the decision to spill water is determined largely by local meteorological circumstances. Class 3 ratings
based on "hazardous water currents" are given on the "likelihood" that such occurrences "may" occur. Due to the dispersal effect as the water enters the reservoir from the spill channels, water currents decrease rapidly and exhibit less severe conditions. However, capability ratings remain Class 3 since the restricting factors have shifted from water conditions to slope and subsurface textural restrictions. Moderate capability ratings exist at only one location (northwest side of the reservoir), with the restricting factors being width of the zone and moderate water currents \( \left( \frac{3}{w} \times \frac{2}{d} \times \frac{1}{A} \right) \).

**LAND MANAGEMENT POLICY RECOMMENDATION FOR THE LITTORAL ZONE**

1. The severity of the currents generated by releases from both dams should be investigated by a team of hydrologists and recreation experts to determine the degree to which various hydro operational conditions affect recreational use of this zone. This could be accomplished at the same time that hydraulic versus recreational uses of the Open Water Zone are also investigated.

**Land-based Landtypes**

(a) The Beach Zone

For reasons discussed earlier (p. 95) beach formation along the reservoir shoreline has been limited. Three beach areas are evident in
the northern portion of the reservoir; two of which occur on the western shore, and the latter occurring on a small mid-channel spit which is subject to rising waters and currents. Access to the shoreline beaches are good with the northern beach being restricted by its exposure and width (see Photos 12 and 13). The second shoreline beach, underlain by fine sands and gravels (alluvium), is presently covered by grasses and small shrubs. As shown by Photos 14 and 15, it is bordered by a wet beach comprised of sands and small stones. Its recreational capability is rated $1A \approx 1G$, with the limiting factor being its northeastern exposure.

LAND MANAGEMENT POLICY RECOMMENDATION FOR THE BEACH ZONE

Examination of subsurface textures of the littoral and immediate open water zone has established that textures become more finer away from the shoreline. Excessive slopes in the littoral zone also give way to a more gradual slope gradient until reaching the old river channel (see explanatory diagram below).

Approximation of Hayward Reservoir Profile
1. It is therefore suggested that reservoir levels be dropped 10-15 feet below the present operating range (140-137 feet ASL) to an operating range of 122-125 feet ASL. This will provide for an increase in the beach zone at various locations around the shoreline, thereby greatly enhancing its recreational potential.

(b) The Subforeshore Zone

The Subforeshore Zone is most evident along the southern and central regions of the reservoir. Widths average between 500-1000 feet, with a mean slope of approximately 30%. On the western shoreline, the predominant rating is $3_{sl}A2_{t}T2_{e}$ with the restricting factors being excessive slopes (sl), textural conditions (t), silty clays and silty clay loams with topographic conditions (e), only enhancing the viewing capability moderately. Class 1 viewing areas occur on both sides of the reservoir near all three dams. On the east side of the reservoir, severe slope conditions are also a restricting factor. However, trails and footpaths are rated Class 1 and 2 due to slopes (30-50%) and surface textures. Trails are somewhat moderately restricted in the northeastern sector (near Steelhead Creek) due to soils being only moderately drained. Camping and picnicking are severely restricted by excessive slope gradients (see Map 8). Class 1 and 2 nature study areas occur along the southeast portions (Harsine Creek—waterfowl nesting and marsh areas) and southwest (old stands of Douglas fir, 120-150 feet in height) regions.
LAND MANAGEMENT POLICY RECOMMENDATION FOR THE SUBFORESHORE ZONE

1. Trails should be developed in only areas rated Class 1 and 2, and should include Viewing and Nature Study areas rated Class 1 and 2 where possible. Where surface textures are moderately restricting, trails should be developed on a gravel base and should follow closely the contours of the landform. Viewing areas (platforms, etc.), should be constructed along the trails and at locations where scenic views present themselves. The location of trails should also be closely associated to beach and foreshore zones that have high capabilities.

2. Trails should only be developed for use by foot or equestrian traffic. These trails may be classed into the following categories:
   (1) wilderness and long-distance hiking trails (connected to the Upland Zone),
   (2) connecting trails (i.e., beach to campsite),
   (3) short hiking and nature trails,
   (4) snowshoeing and cross-country ski trails.

(c) The Foreshore Zone

The Foreshore Zone comprised over 50% of the total land surface within the Reservoir Site Region. Average slopes are less than 15% with
land promontories and creek gullies prominent in all areas. The Fore­shore Zone offers a wide range of recreational activities with varying degrees of capability. Class ratings range from $1c \, 1p \, 1t$ (no limitations for campgrounds, picnic sites and trails) to $3c \, 3v \, 2t$ (severe limitations to camping (slowly permeable soils), restricted viewing due to topographic conditions, and moderate capability for trails due to soil textures.

In general, the east side of the reservoir offers a higher capability for recreational use, although soil conditions do contribute to varying degrees of severity for recreational use. Nature study areas were classed as Class 2 with slope and moderately permeable soils being the restricting factors. Viewing areas Class 1 occurred where rock outcrops and/or scenic vistas of the lake were afforded. Trails were rated predominantly Class 1 and 2 with some Class 3, with slope and soil texture moderately restricting use (Map 9 and Photo 16).

On the west side of the reservoir, the recreational capability of the foreshore was generally lower. This was accounted for by the Whatcom soils series: a silty clay, silty clay loam soil with slow permeability. The soil is moderately well drained (with imperfectly drained areas in the low lying regions), with water perching in the upper solum being common. As a result, intensive recreational activities are severely restricted. Two nature study areas are rated Class 1 (large Douglas fir stands). Scenic viewing is rated Class 3 as a result of topographic conditions (undulating slopes that restrict any sight of the
MAP 9.
RECREATION CAPABILITIES
FORESHORE ZONE
trails and pathways are predominantly rated Class 2 with soil texture restrictions.

LAND MANAGEMENT POLICY RECOMMENDATION FOR THE
FORESHORE ZONE

1. That intensive development for campground and picnic facilities be limited to the southeastern section of the site region, and only in Class 1 areas. Access to the water is limited due to excessive slopes although requirements for trails and footpaths through the preforeshore
are rated Class 1 and 2. Trails should run linearly along the shoreline to take advantage of the views where possible. Trails should also include nature study areas.

2. That selective logging take place in Class 1 areas for campgrounds in order to "thin out" and prepare the site for future recreational use.

3. That on the west side, foreshore activities be limited to footpaths, trails and viewpoint of the reservoir and hydro generating facilities.

4. That access points to the water rated Class 1 be developed where adequate parking and turnabout space is available.

(d) The Upland Zone

The Upland Zone provides a wide range of hiking trails and paths, and scenic vistas of the Reservoir Site Region. The Upland Zone in the northeastern sector in general is rated moderate for such activities, except where slopes and unstable ground conditions are severe. Unorganized hiking is restricted moderately, due to unstable ground conditions, slowly permeable soils, and excessive stoniness. Similar conditions exist on the southwest upland zone. Scenic views of the reservoir and surrounding region are afforded from outcrops, land promontories (ridges), and from the general lie of the land (see Map 10).
LAND MANAGEMENT POLICY RECOMMENDATION FOR THE
UPLAND ZONE

1. That the Upland Zone be developed at the same rate that
demands for paths and trails increase due to excessive
use of such facilities in the foreshore and preforeshore
zones of the reservoir site region.

SUMMARY

In this chapter, the recreation classification framework has
been applied to a case study. In the initial analysis, the results
suggest that the Reservoir Site Region can be classified into distinct
zones. Furthermore, within these zones, a capability rating may be
assigned for selected recreation activities based on various biogeo-
physical attribute values. While these findings are by no means con-
clusive, they nonetheless provide the necessary background data for a
more complete study of the Site Region. Such a study would naturally
include those conditions necessary for implementation of an integrated
reservoir management plan. These conditions are developed further in
the concluding chapter.
CHAPTER FIVE

MANAGEMENT CONDITIONS FOR INTEGRATED RESERVOIR USE

This thesis has developed a methodology for the classification of land-use capabilities for recreation at reservoirs. It is suggested that such an approach be the initial phase (followed by suitability and feasibility analysis) in assessing future land management options for the maximum benefit of a referrent group. Furthermore, it is proposed that integrated reservoir use provides an alternative to the traditional single-purpose use of reservoirs.

Implicit in a discussion of integrated use are the necessary management conditions for policy implementation. Some of these requirements have already been discussed (p. 17). However, recognized in this thesis are five (5) additional conditions for integrated reservoir management. The salient points of each are discussed as pertaining to recreation within the Reservoir Site Region.

1. Reservoir clearance programs,
2. Sedimentation control,
3. Regulated flows for Optimal Water Resources Allocation,
4. Water-surface Zoning and Activity Segregation,
5. Design Standards.
RESERVOIR CLEARANCE

In the past, few provisions were made for reservoir clearance, and such clearance when undertaken was normally on the instigation of the operating agency to ensure efficient and safe operation of the hydro-generating facility. Under the present system, various requirements have been established by the British Columbia Water Comptroller before a water licence is issued to the responsible agency. This schedule allows for the surcharging of the reservoir and for the initial erosion on beaches and the stabilization of the angle of repose of shorelines. The Peace and Arrow Projects are noteworthy in that for the first time it is instructed that clearing be completed in a specific time after the initial flooding (Bakewell, 1965). Such a schedule was also instrumental in the planning of pulp mills on Williston Lake, B.C., where pre-clearance was stipulated by the log-towing companies and pulp mill officials as a necessary condition for navigation on the reservoir.1 Reservoirs developed at the beginning of the century in British Columbia, which are now approaching the stabilized stage have also received, or are in the process of receiving, some form of clearance program. In many cases, the reliance from outside help2 has accelerated these programs.

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1 From discussion with J. Dah, General Manager, Finlay Forest Industries, Mackenzie, British Columbia.

2 British Columbia Penitentiary inmates have been involved in clearance programs at Stave Lake since 1970.
The debris problem, both standing and floating vegetation, is accentuated by a number of factors:

1. Most of the recent developments in the province, are located in heavily forested areas, and as expected, proportionally larger quantities of floating debris are likely to occur.

2. Those reservoirs exposed to harsh winters (especially in the interior and northern parts of the province) are subjected to shoreline erosion from snow and ice. Due to erosional forces, these conditions increase the build-up of woody material on the surface of the reservoir, as well as accumulations of submerged debris on the lake bottom.

3. The exposure of a reservoir to winds adds to unprecedented hazards in that wave action conceals both floating and submerged woody material. These conditions naturally increase the degree of limitation for integrated use, particularly for navigation and recreation purposes.

Reservoir clearance can be divided into two major categories: pre-flood and post-flood clearing. Pre-flood clearing involves removal and disposal of woody material from the reservoir area before filling. In some cases, the wood is prepared for floatation prior to filling of the reservoir. In post-flood clearing, the removal and disposal of floating material and stumps is accomplished by:
(a) corralling and sinking
(b) beach and burning
(c) loading and burning out
(d) individual stump removal.

The advantages of reservoir clearance have been alluded to in Planning and Construction (p. 30). Additional advantages may be summarized as follows:

- reservoir clearance reduces the possibility of debris collecting over the trash racks located in the dam, and thereby interfering with the efficiency of the power generating facilities,

- clearance prevents the decomposition of organic matter which may create undesirable tastes or odors in the water (K. Linsley, J. Franzini, 1972),

- clearance reduces the unsightly appearance of standing trees and stumps in the water which also restrict operation of commercial fisheries, recreation and navigation,

- reservoir clearance increases the storage capacity of the pool. The volume of wooded material is calculated prior to flooding to determine the losses in storage capacity if clearance is not undertaken. This amount though is very small.
- pre-flood clearance increases the access and ease to which development and preparation of sites on the reservoir shoreline can be accomplished (i.e., dock facilities, industrial plant sites, recreation sites, and so on).

- reservoir clearance increases the integrated use potential of the water impoundment and encourages the facilitation of such management alternatives.

SEDIMENTATION CONTROL

The ultimate destiny of all reservoirs is to be filled with sediment since every stream carries with it a suspended load as well as larger solids along the stream bed (referred to as bedload). When the sediment-laden water reaches the reservoir, the velocity and turbulence of the stream is greatly reduced. There is a natural tendency for the larger suspended particles and most of the bedload to be deposited in the transition zone between the riverine and lacustrine areas. The net result is the formation of a delta at the head of the reservoir. The finer clays and silts are kept in suspension longer, and are deposited further down the reservoir. Some finer particles may be kept totally in suspension and are carried past the dam (see Figure 16).

An understanding of the sedimentation process in a reservoir is important to the water resources manager for at least three (3) reasons. In the first place, while certain portions of the reservoir pool are usually designated for sediment storage, sediment deposition is
Figure 16. Schematic drawing of the sediment accumulation in a typical reservoir (Linsley, Franzini, 1972).

indiscriminate and is a function of the physiochemical properties of the sediment. For this reason, sediment deposition does not always take place in the dead storage capacity of the reservoir, but is deposited in different vertical zones in the reservoir (see Figure 17), each having a series of impacts on both the operations of the plant and other uses of the water and adjacent lands.

Secondly, as indicated above, sediment accumulation can impact on the operation of the physical plant to the extent that useful storage capacity is lost to sediment deposits. Whereas the range of the reservoir drawdown will remain constant since this is determined by the level of the sluiceways, as a reservoir fills with sediment, the amount of water necessary to generate the same power will increase, thereby increasing the rate at which the reservoir is drafted. Since power generation demands begin to increase in the fall, this would mean a faster rate of drawdown during the latter part of the recreation season.
Backwater effect

Streambed

Reservoir under initial conditions.
No sediment deposited.

Reservoir partially filled with sediment.
Dominantly in course particle sizes.

Reservoir partially filled with sediment.
Dominantly in silt and fine particle sizes.

Reservoir partially filled with sediment.
Dominantly in silt and clay particle sizes.

Reservoir filled with sediment
At this stage trap efficiency becomes zero and remaining available storage is maintained by sluicing at outlets.

" a - FLOOD CONTROL SPACE
b - CONSERVATION STORAGE
c - INACTIVE STORAGE
d - DEAD STORAGE
== OUTLETS"

Figure 17. Sedimentation Conditions

An understanding of the sedimentation process for an integrated reservoir management program is even more crucial since other uses would be affected by the availability of usable water.

In a reservoir where the entire operating storage is reserved for one purpose, the location of the sediment deposited in a reservoir might not be important. In multiple purpose reservoirs, however, where the storage in varying zones of elevation is reserved for individual purposes such as power production, irrigation, recreation, and flood control, it is desirable to know just how much storage will be lost in each zone owing to sedimentation and what the backwater effect on upstream facilities might be (Bondurant and Livesey, 1973).

Finally it must be remembered that fine silts and clays have contributed to the rich alluvial farm lands in many valley bottoms. The Fraser Valley in southwestern British Columbia bears tribute to this phenomenon. The impoundment of water behind a dam artificially impedes this sediment flow, causing a build-up within the reservoir. Failure to release sediments from the reservoir may have several effects on the downstream biology. These include the lack of silt which is essential in maintaining the stability and fertility of soil on the alluvial river banks, reduction in nutrient levels, and changes in the estuarine environment (Midgley, 1972).

Unfortunately reservoir sedimentation cannot be prevented, although it may be retarded. One way to accomplish this is to select those sites where the sediment inflow is low.

Some basins are more prolific sources of sediment than others because of soil type, land slopes, vegetal cover, and rainfall characteristics (Linley and Franzini, 1972).
Soil conservation within the river basin can also retard the sediment inflow into the reservoir using such techniques as terracing, strip cropping and contour plowing. In addition, heavy vegetal cover in the catchment area impedes overland water flow and erosion. Special sluiceways designed within the dam and located at various levels may also permit the finer sediments to be discharged past the dam. The physical removal of sediment is rarely feasible and even at the most favourable of prices, removal by existing methods would not prove economical.

REGULATED FLOWS FOR OPTIMAL WATER RESOURCES ALLOCATION

The problem of determining optimum allocation of water resources for multiple purposes is a subject of continuing research. However, given the objective that integrated uses are desirable, the solution lies in allocating the resource in such a way that the net benefits to society are maximized (economic, environmental, and social). Such a policy would involve regulations regarding the timing, and releases of water, the available storage, as well as a maintained level of water quality.

Research into the combined effects of maintained water levels as pertaining to integrated uses has not received adequate attention. In this field, the emphasis has been on developing mathematical models in determining optimal uses based on multiobjectives and maximizing benefit-costs. These techniques are by and large still theoretical although they do provide the necessary framework for applied research.
Hall (1968), proposes that the application of linear programming can help to determine the set of decisions regarding releases of water from the reservoir that will maximize the total economic returns from operations (subject to physical, legal and social constraints). It is further developed that use of such a procedure can help to optimally integrate complex systems of reservoir management (including fish and wildlife enhancements, recreation, salinity control, pollution control, etc.).

Eastman and ReVelle (1973), develop an empirical model that minimizes the reservoir's storage capacity subject to constraints designed to meet the needs of water supply, recreation and flood control. The applicability of the model is greatest when such uses are all desirable features of the project.

Mobasheri and Harboe (1970), develop a mathematical model to help in determining the optimum design and operation of a multipurpose reservoir. The development purposes include water supply, hydropower production, flood control, and low flow augmentation. It takes into consideration the fact that water released from the reservoir can serve more than one purpose. Furthermore, it suggests that the economic returns from a project are a function of both design and operational rules of the project.

Marshall (1973), examines the concept of cost sharing at multiple objective reservoirs. The primary objective is to demonstrate how a cost-sharing rule can be designed to induce local interests to select the most efficient project based on three criteria; environmental quality,
regional economic development, and social well-being. The importance of this approach is that it firstly encourages local interests to select the nationally efficient project, and secondly, it encourages these local interests to apply pressures to the planners in the construction agencies to keep possibly inflated benefit figures at reasonably accurate levels. This approach would have particularly relevant significance in its application to Integrated Resources Management.

The application of combining simulation and mathematical programming techniques has not received adequate attention (Mobasher and Harboe, 1970). This is probably the result of a lack of supportive evidence and research in the field of optimal water resources allocation, as well as a reluctance to test the techniques for an all-purpose integrated reservoir system in view of existing administrative conflicts.

It has been the purpose of this section to highlight some of the research that deals with water releases for integrated uses and to suggest that such alternative systems are in the realm of reservoir management. As noted in Chapter One, the basic factor of integrated-use is a "compromise" which permits reasonable efficiency in operation for each use rather than maximum efficiency for a single purpose.

WATER-SURFACE ZONING AND ACTIVITY SEGREGATION

The framework developed in this thesis allows the water surface of reservoirs to be classed into management units based on biogeophysical restrictions. While these restricting factors per se can affect the degree of on-water activities, the classification technique
does not separate conflicting recreational uses within the same management unit (e.g., water-skiing versus canoeing in the Open Water Zone).

Another method for classifying the on-water area of a reservoir, while having similar aspects to the method developed in this thesis, has the added advantage of separating conflicting on-water activities. This approach deals with activity, segregation, and is referred to as "water zoning." According to Jaakson (1972):

... the key to water-use zoning is to divide incompatible activities into groups which exhibit similar characteristics and which take place under similar circumstances.

Three zones are recognized in the "zoning approach" to controlling on-water recreation (Jaakson, 1972). Briefly they are as follows:

(1) The Shoreline Activity Zone. Since the shoreline is that area where the concentration of water-oriented recreation is the greatest, management objectives are necessary to minimize conflicts between sedentary and slow moving (swimming, sunbathing, wading, etc.) and high speed water activities (water skiing, power boating, etc.). The overlap of these recreational activities along the shoreline also adds to its potential for accidents, and strengthens the argument in favour of stricter controls. Furthermore, vulnerable shallow-water area plant and animal life can be partly protected by a shoreline activity zone designed to minimize water activity conflicts. Three factors are involved in the designation of a Shoreline Activity Zone:
(a) Motorboat activity should be limited to a maximum speed of 5 mph.

(b) Boat movement within this zone should be limited to travel at right-angles to the shore, as far as this is practical along the given shoreline configuration. Movement would therefore be restricted to boats approaching and departing from docks, launching ramps, etc.

(c) A distance of 250-500 feet from shore is recommended for this zone.

The Shoreline Activity Zone is similar to the Littoral Zone classification used in this thesis except that the lateral extent of the former is determined linearly rather than to the five foot contour depth.

(2) The Open Water Zone. This zone refers to the centre of most lakes beyond the shoreline activity zone, and is designated as "unrestricted use" of the water. Although a number of boating activities take place in this zone, it is difficult to separate these on the basis of speed. However, the control of water activities can be made more plausible by relating the dimension of this zone to the configuration of the shoreline and lake morphology. Whereas large round lakes render activity control difficult, lakes with bays, inlets, and headlands make activity segregation easier. The use of shoreline ratios (based on the number of irregularities per mile of shoreline) would be one method in establishing the dimensions of this zone (Adams, Zoltai, 1969).

(3) The Wilderness Zone. While the purpose of the Shoreline Activity Zone and Open Water Zone is to minimize potential conflicts between
on-water activities which are incompatible due to their spatial requirements and speed characteristics, the purpose of the Wilderness Zone is to protect the ecosystem of a lake from adverse consequences as a result of recreational activities. This zone should therefore include those sections of the lake where wildlife is most vulnerable to the effects of recreation. This would include the Littoral Zone where aquatic vegetation is present since it is in this habitat where both producer and consumer organisms are significant. Recreation in this zone should be restricted to those activities that are sedentary or slow moving: canoeing, fishing, and nature study. All high-speed activities that tend to develop high densities should be strictly restricted in this zone.

THE IMPLEMENTATION OF RESERVOIR ZONING

It is recognized that implementation of such water surface zoning will pose many legal, technical and administrative difficulties. While plan implementation is peripheral to this study, it should be pointed out that the administration and management of a reservoir in British Columbia raises serious problems since no one administrative agency is solely responsible. As a result, recreational use at reservoirs in the province has developed in a haphazard fashion with all the conflicting issues (both on and around the reservoir) being visible. Given that such administrative mechanisms are provided, a solution to the technical problems can be provided in part by the use of buoys of different shapes and colours, with signs being located
on the shore and placed to be both easily visible and yet meld with
the background. Other aids in the implementation could include the
publication and free distribution of "lake pamphlets" which:

... describe in simple written and map format what activity
and area restrictions exist. A system of fines and other penalties
for the violation of water-use regulations appears obligatory, if
the measures are to be effective (Jaakson, 1972).

The significance of water zoning is that it enables the land-use planner
to separate incompatible activities into groups which exhibit similar
characteristics. Furthermore, it can be used in conjunction with the
classification technique established in this thesis by separating those
activities that have high capabilities within the same management unit.

DESIGN STANDARDS

The implementation of an Integrated Reservoir Management scheme
involves the establishment of both the administrative and technical
aspects of the water resource base. Some of the more common requirements
as pertaining to recreational use have been discussed in the previous
sections. These conditions are by no means all-inclusive nor definitive
on the subject. However, they do cover the more pertinent aspects of
integrated use. In the final analysis, consideration must also be given
to proper design standards for recreation in that ultimately the design
and layout of facilities affects the degree to which the resource base
can be maintained at a desired level of quality. This level of quality
is determined initially by the "carrying capacity" of the recreation
resource to sustain certain levels of use without permanent damage, and that this "natural" capacity:

... can be increased through design and/or structural interventions by management; and that the recreationists' perception of the quality of the facility and level of use are important considerations in establishing the "designed capacity" of any recreational use (Verburg and Rees, 1974).

With increasing concerns in recent years for environmental preservation, there has been a corresponding increase in the need for information on standards used by recreation planners, authorities, and organizations throughout the country. Much of the research, undertaken by government agencies and planning departments in the United States, has been adopted by the Parks Branch and Regional Districts of British Columbia. By way of example, the following table, taken from the U.S. Forest Service, illustrates the degree of development for campgrounds and picnic sites and the necessary level of environmental modification. For a more comprehensive index to guidelines for outdoor recreational facilities, see Verburg and Rees (1975), The Carrying Capacity of Selected Outdoor Recreation Facilities.

SUMMARY AND CONCLUSIONS

This thesis has demonstrated the practical application of a developed framework for a specific resource. Furthermore, it has been established that the resource base of the Reservoir Site Region creates opportunities to achieve integrated uses. The initial establishment of these opportunities is defined on the basis of capability (supportive
### TABLE 9

<table>
<thead>
<tr>
<th>LEVELS OF ENVIRONMENTAL MODIFICATION</th>
<th>DEVELOPMENT SCALE</th>
<th>LEVELS OF RECREATION EXPERIENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum site modification. Rustic or rudimentary improvements designed for protection of the site rather than comfort of the users. Use of synthetic materials avoided. Minimum controls are subtle. No obvious means regimentation. Spacing informal and extended to minimize contacts with others. Motorized access not provided or permitted.</td>
<td>1 primitive</td>
<td>Primitive forest environment is dominant. Rudimentary and isolated development sites beyond the sight or sound of inharmonious influences. Maximum opportunity for experiencing solitude, testing skills and compensating for the routines of daily living. User senses no regimentation. Feelings of physical achievement in reaching site is important.</td>
</tr>
<tr>
<td>Little site modification. Rustic or rudimentary improvements designed for protection of the site rather than comfort of the users. Use of synthetic materials avoided. Minimum controls are subtle. Little obvious regimentation. Spacing informal and extended to minimize contacts with others. Motorized access provided or permitted. Primary access over primitive roads.</td>
<td>2 secondary primitive</td>
<td>Near primitive forest environment. Outside influences present but minimized. Feeling of accomplishment associated with low standard access is important but does not necessarily imply physical exertion to reach site. Opportunity for solitude and chance to test outdoor skills is present.</td>
</tr>
<tr>
<td>Site modification moderate. Facilities built equally for protection of site and comfort of users. Contemporary/rustic design of improvements is usually based on use of native materials. Inconspicuous vehicular traffic controls usually provided. Roads may be hard surfaced and trails formalized. Development density about 3 family units per acre. Primary access to site may be over high standard well traveled roads. VIS, if available, is informal and incidental.</td>
<td>3 intermediate</td>
<td>Forest environment is essentially natural. Important that a degree of solitude is combined with some opportunity to socialize with others. Controls and regimentation provided for safety and well-being of user sufficiently obvious to afford a sense of security but subtle enough to leave the taste of adventure.</td>
</tr>
<tr>
<td>Levels of Environmental Modification</td>
<td>Development Scale</td>
<td>Levels of Recreation Experiences</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Site heavily modified. Some facilities designed strictly for comfort and convenience of users but luxury facilities not provided. Facility designs may tend toward and incorporate synthetic materials. Extensive use of artificial surfacing of roads and trails. Vehicular traffic controls present and usually obvious. Primary access usually over paved roads. Development density 3-5 family units per acre. Plant materials usually native. Visitor Information Services frequently available.</td>
<td>4</td>
<td>Forest environment is pleasing and attractive but not necessarily natural. Blending of opportunities for solitude and socializing with others. Testing of outdoor skills on site mostly limited to the camping activity. Many user comforts available. Contrast to daily living routines is moderate. Invites marked sense of security.</td>
</tr>
<tr>
<td>High degree of site modification. Facilities mostly designed for comfort and convenience of users include flush toilets; may include showers, bath houses, laundry facilities, and electrical hookups. Synthetic materials commonly used. Formal walks or surfaced trails. Regulation of users is obvious. Access usually by high speed highways. Development density 5 or more family units per acre. Plant materials may be foreign to the environment. Formal VIS services usually available. Designs formalized and architecture may be contemporary. Mowed lawns and clipped shrubs not unusual. (Class 5 sites only provided in special situations or close to large cities where other lands are not available.)</td>
<td>5</td>
<td>Pleasing environment attractive to the novice or highly gregarious camper. Opportunity to socialize with others very important. Satisfies urbanites need for compensating experiences and relative solitude but less intensive than in classes 1-4. Obvious to user that he is in secure situation where ample provision is made for his personal comfort and he will not be called upon to use undeveloped skills.</td>
</tr>
</tbody>
</table>
systems) analysis. The capability approach developed is a significant contribution given that the management objective is to maximize the net benefits from the resource base for public use. The degree of limitation for recreational capabilities is determined on the basis of selected attribute biogeophysical values. This approach recognizes that capability analysis is the logical initial phase in determining resource-use of the land, and tends to minimize adverse environmental impacts. Secondly, an approach that incorporates land capability with social and economic realities as a governing factor in optimizing land-use implies a sustained yield plus maximum social benefits from the land and associated resources for a referrent group.

The biogeophysical values used in this study to establish land management units for recreation provided a useful, although limited foundation, for assessing the ecological considerations of land-use capability. In the future development of the classification framework, the ecological concepts of reservoirs discussed in Chapter Two should be given more accurate and detailed analysis than was used in this study, especially regarding aquatic vegetation and organisms in the littoral zone, shoreline and beach formations, and the surface and sub-surface water currents in the reservoir. Ultimately, the identification framework should involve a complete assessment of not only the recreation capabilities of the reservoir (which form one part of integrated management), but also the total uses of the water resource base for the maximum benefit of society.
Bibliography


APPENDIX 1

THE COMPONENTS OF THE BASIN HYDROLOGICAL CYCLE
Figure 18. The Components of the Basin Hydrological Cycle

APPENDIX 2

GROUND DRAINAGE CLASSES
**GROUND DRAINAGE CLASSES**

<table>
<thead>
<tr>
<th>Drainage class</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessively drained</td>
<td>Water is removed from the ground very rapidly. Most excessively drained ground is very porous or occurs on steep slopes, or both, and is free of mottlings.</td>
</tr>
<tr>
<td>Somewhat excessively drained</td>
<td>Water is removed from the ground rapidly. Most somewhat excessively drained ground is sandy and very porous, and free of mottling through the profile.</td>
</tr>
<tr>
<td>Well-drained</td>
<td>Water is removed from the ground readily, but not rapidly. Most well-drained ground is intermediate in texture and is free of mottling to depths of several feet.</td>
</tr>
<tr>
<td>Moderately well-drained</td>
<td>Water is removed from the ground somewhat slowly, and it is wet for a small but significant part of the time. Most moderately well-drained ground has a slowly permeable layer at a depth of 2 to 3 feet, a relatively high water table, additions of water through seepage or combinations thereof. Most moderately well-drained ground is mottled at depths of 2 to 3 feet.</td>
</tr>
<tr>
<td>Imperfectly or somewhat poorly</td>
<td>Water is removed from the ground slowly enough to keep it wet for significant periods, but not all the time. Most imperfectly or poorly drained ground has a slowly permeable layer at a depth of 1 to 2 feet, a high water table, additions through seepage, or combinations thereof. Most of the imperfectly, or somewhat poorly, drained ground is mottled at depths of 6 to 16 inches.</td>
</tr>
<tr>
<td>Poorly drained</td>
<td>Water is removed from the ground so slowly that it remains wet for a large part of the time. In poorly drained ground, the water table commonly is at, or near, the surface during a considerable part of the year and is due to a high water table, to a slowly permeable layer, to seepage, or to some combination thereof. Poorly drained ground is light gray from the surface downward, with or without mottlings.</td>
</tr>
<tr>
<td>Very poorly drained</td>
<td>Water is removed from the ground so slowly that the water table remains at, or near, the surface most of the time. Most very poorly drained ground occurs in level, or depressed, sites, frequently ponded. Most very poorly drained ground has dark-gray or black surface layers and is light gray, with or without mottlings, in deeper parts.</td>
</tr>
</tbody>
</table>

APPENDIX 3

CLASSES OF STONINESS
CLASSES OF STONINESS

Classes of stoniness are outlined as follows:

Class 0. No stones or too few to interfere with tillage. Stones cover less than 0.01 percent of the area.

Class 1. Sufficient stones to interfere with tillage but not to make intertilled crops impracticable. (If stones are 1 foot in diameter and about 30 to 100 feet apart, they occupy about 0.01 to 0.1 percent of the surface, and there are about 0.15 to 1.5 cubic yards per acre-foot).

Class 2. Sufficient stones to make tillage of intertilled crops impracticable, but the soil can be worked for hay crops or improved pasture if other soil characteristics are favorable. (If stones are 1 foot in diameter and about 5 to 30 feet apart, they occupy about 0.1 to 3 percent of the surface and there are about 1.5 to 50 cubic yards per acre-foot).

Class 3. Sufficient stones to make all use of machinery impracticable, except for very light machinery or hand tools where other soil characteristics are especially favorable for improved pasture. Soils with this class of stoniness may have some use for wild pasture or forests, depending on other soil characteristics. (If stones are 1 foot in diameter and about 2.5 to 5 feet apart, they occupy about 3 to 15 percent of the surface, and there are about 50 to 240 cubic yards per acre-foot).

Class 4. Sufficient stones to make all use of machinery impracticable; the land may have some value for poor pasture or for forestry. (If stones are 1 foot in diameter and are about 2.5 feet or less apart, they occupy 15 to 90 percent of the surface, and there are more than about 240 cubic yards per acre-foot).

Class 5. Land essentially paved with stones that occupy more than 90 percent of the exposed surface (Rubble).