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Methodologies for Assessing the Cumulative Environmental Effects of Hydroelectric Development of Fish And Wildlife in the Columbia River Basin

Volume 2: Example and Procedural Guidelines

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METHODOLOGIES FOR ASSESSING THE CUMULATIVE ERVIRONMENTAL EFFECTS OF HYDROELECTRIC DEVELOPMENT ON FISH AND WILDLIFE IN THE COLUMBIA RIVER BASIN

Volume 2: Example and Procedural Guidelines

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Volume 2: Example and Procedural Guidelines

by

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ABSTRACT

This volume is the second of two volumes that address methods for assessing the cumulative effects of hydropower development on fish and wildlife in the Columbia River Basin. A hypothetical example of multiple hydroelectric development is used to demonstrate the applicability of the integrated tabular methodology (ITM) that was recommended for cumulative effects assessment in Volume 1. The example consists of an existing mainstem dam and four proposed small hydroelectric developments in a small river basin containing elk summer and winter range and chinook salmon spawning areas. Single-project impact assessments are used collectively in the methodology to estimate the cumulative effects of the projects on elk and salmon. The steps in cumulative assessment are (1) establishing a conceptual and schematic representation of each cumulative effect, (2) calculating interaction coefficients for each pair of projects, (3) developing interaction and impact matrices, (4) multiplying these matrices, (5) evaluating the contribution of shared project features to cumulative effects, and (6) incorporating the effects of already existing projects. The ***ITM*** is most effective when sin&-project assessments are accomplished in a detailed, quantitative manner. The methodology involves the use of impact response curves (such as fry emergence as a function of fine sediment or habitat suitability as a function of road density) for each impact being assessed. However, it is possible to accomplish cumulative assessment without the use of response curves if less detailed or only qualitative information is available.

1 INTRODUCTION

The purpose of this document is to assist the Bonneville Power Administration (BPA) with its responsibilities mandated in the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (P.L. 96-501). This legislation led to the development of the Columbia River Basin Fish and Wildlife Program, under which BPA was directed to fund a study to develop criteria and methods for assessing the cumulative environmental effects of multiple hydroelectric developments within the basin. The Hydropower Assessment Steering Committee of the Northwest Power Planning Council outlined an approach to this study, which included seven tasks:

1. Identify species and habitats that are cumulatively affected by hydroelectric development,

2. Identify the types of environmental effects associated with hydroelectric development,

3. Identify the interactions among hydroelectric development and other activities in the river basin,

4. **Describe existing assessment techniques for use in cumulative *effects* assessment,**

5. Evaluate the applicability of existing assessment methodologies to the Columbia River Basin,

6. Develop a stock/recruitment model as a cumulative effects indicator, and

7. Recommend two cumulative ***effects*** assessment methodologies ***for*** use in the Columbia River Basin.

The results of these seven tasks are reported in Volume 1 of this report. That volume concluded with a recommendation that none of the existing methodologies for cumulative effects assessment is entirely applicable to the study of hydropower effects on the fish and wildlife of the Columbia River Basin. Needed instead is a methodology that is applicable to any combination of the 40 species or groups and 27 effects of hydropower development identified in Volume 1. The methodology also should incorporate the type of information used in and derived from the assessment of single hydropower projects (called single-project assessment). Volume 1 developed the concept of an integrated tabular methodology ***(ITM),*** which can be used for all species and effects of hydropower development.

The ITM is a matrix-based procedure for accumulating incremental, single-project effects into a total that represents the cumulative effect of all projects acting together. The procedure was suggested by the definition of the term cumulative effect on which the study was based, i.e.,

> an environmental change resulting from the accumulation and interaction of the effects of one action with the effects ***of*** one or more other actions occurring on a common resource.

The word interaction in this definition expresses the concept that the cumulative effects of multiple developments may be greater than the sum of the individual, single-project effects. This concept, derived from ecosystem ecology, has repeatedly been suggested by fiih and wildlife managers as a primary reason why single-project assessment is not sufficient for protecting fish and wildlife resources.

The ITM incorporates-the concept of project interactions through the use of interaction coefficients that represent the ability of two projects to modify each other's impacts. The interaction coefficients (e.g., $C_{1,2}$ for projects 1 and 2) are placed in an ***interaction matrix*** that is multiplied by an impact matrix, which contains values representing the single-project impacts of the various projects (e.g., I_1 for project 1). The example below is for three projects.

$$\underset{\text{Impact Matrix}}{\begin{bmatrix} I_1 & I_2 & I_3 \end{bmatrix}} \times \underset{\text{Interaction Matrix}}{\begin{bmatrix} 1 & C_{1,2} & C_{1,3} \\ C_{2,1} & 1 & C_{2,3} \\ C_{3,1} & C_{3,2} & 1 \end{bmatrix}}$$

$$\text{Product Matrix} \quad = \begin{bmatrix} \begin{pmatrix} I_1 \\ + \\ I_2C_{2,1} \\ + \\ I_3C_{3,1} \end{pmatrix} \begin{pmatrix} I_1C_{1,2} \\ + \\ I_2 \\ + \\ I_3C_{3,2} \end{pmatrix} \begin{pmatrix} I_1C_{1,3} \\ + \\ I_2C_{2,3} \\ + \\ I_3 \end{pmatrix} \end{bmatrix} \qquad (1.1)$$

The sum of three elements in the product matrix is the estimate of the cumulative effect of all projects acting **together:**

$$\text{Cumulative effect} = I_1 + I_2 + I_3 + I_1C_{1,2} + I_1C_{1,3} + I_2C_{2,1} + I_2C_{2,3} + I_3C_{3,1} + I_3C_{3,2} \qquad (1.2)$$

The single-project impacts are derived through single-project assessments, in which existing models are used to estimate either population effects or habitat effects of hydropower development. These single-project effects are then accumulated in matrix form as shown above and used, as explained, to derive estimates of cumulative effects.

Interaction matrices can be used for assessments of various types of cumulative effects, including changes to a habitat or changes to a population. The flexibility of the ITM and its potential for producing an explicit calculation of cumulative effect were the factors leading to its recommendation for the Columbia River Basin in Volume 1.

The purpose of the current volume is to describe the use of the ITM for assessing the cumulative effects of hydroelectric development on fish and ***wildlife.*** Section 2 describes project interactions and their determination as a basis for explaining the method of calculating cumulative effects, and Rec. 3 presents general procedural guidelines ***for*** applying the ITM. Then, in Secs. 4 and 5, a hypothetical example of multiple hydropower development is presented that is similar to existing **proposals** for hydropower projects in the Columbia River Basin. The example consists of an existing mainstem dam and ***four*** proposed small hydroelectric projects that would generate power by diverting stream flows around a stream reach with a steep gradient or falls. Although some aspects of the four hypothetical projects in the example may appear similar to those of hydropower projects actually proposed for development, the hypothetical project impacts on fish and wildlife have no relationship to the expected impacts of any real project, either existing or proposed. The example considers only the effects of hydropower development, but other important activities (e.g., forestry operations or mining) could be included in an ITM application. Section 6 discusses some general issues associated with cumulative effects assessment. Appendix ***A*** contains a list of symbols used in the discussion.

2 DETERMINATION OF PROJECT INTERACTION

2.1 MODELS OF BIOLOGICAL RESPONSE TO ENVIRONMENTAL CHANGE

The effects on a species of incremental environmental changes induced by the development of several hydropower projects will depend on the type of response exhibited by the species to those changes. Many methods of single-project assessment contain models of these responses, e.g., the Instream Flow Incremental Methodology and the Habitat Evaluation Procedures described in Volume 1. Other response models result from laboratory or field studies that correlate the physiological or ecological state of a species with environmental conditions. These response relationships are often derived by statistical curve-fitting. In this report, response relationships in the form of graphs or equations, as well as univariate and muitivariate response models, are called response curves. Response curves can be rising, falling, or a combination of both. For example, weighted usable area curves, which are part of the Instream Flow Incremental Methodology, often show increasing weighted usable area with increasing stream discharge. In contrast, sedimentation response curves may show fry emergence from redds decreasing with increasing levels of fine sediment, or fines (i.e., material less than 6.5 mm in diameter).

Some response curves are linear. For example, in Sec. 4.3.1, an equation is given that describes habitat suitability for elk as a function of road density. This equation yields a straight line at road densities of less than 0.62 km/km^2 of elk habitat (Fig. 4.5). Throughout the range of environmental conditions included in such a relationship, the same degree of environmental change will produce the same degree of effect on the species. Therefore, several increments of environmental change occurring together will produce the same effect on the species as if those increments had occurred separately and independently. **Figure** 2.1 **illustrates** a linear response curve with the environmental state indicated by the abscissa and the population's response by the ordinate. If one project has an impact that changes the environment from E_0 to El, then the population response to the environment would change from R_0 to R_1. If another project has an impact that changes the environment from E_0 to E_2, then the population response to the environment would change from R_0 to R_2. If both projects are built together, then they **would** have a combined effect that changes the environment to $E_{1,2}$ (where El $_2$ = El + E_2). The corresponding effect on the population would be a change in population response from R_0 to $R_{1,2}$. This combined effect is called

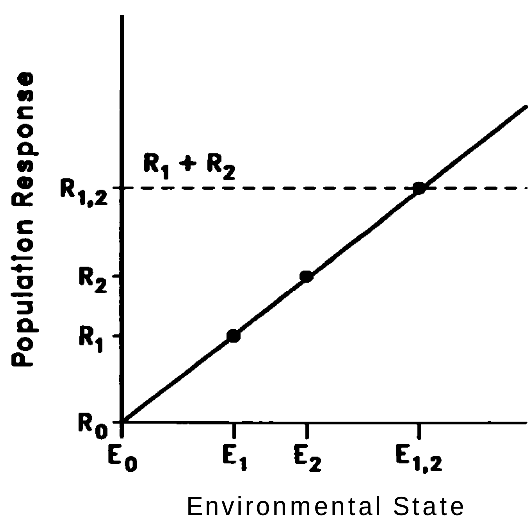

FIGURE 2.1 Example of a Linear **Response** Curve $(R_1 + R_2 = R_{1,2})$

an additive cumulutive effect because the curve is linear, with $R_{1,2} = R_1 + R_2$ That is, the combined effect of the two projects is equal to the sum of their single-project effects.

If a nonlinear relationship exists between the population of a species and the environmental conditions to which that species is exposed, then cumulative effects are not additive, and the response of the population to the combined effect of two projects on the environment $(R_{1,2})$ would not be equal to the sum of its responses to the single-project effects of each project $(R_1 + R_2)$. Figure 2.2 illustrates an exponential response curve, where the slope of the line increases as the independent variable increases in value. At the upper end of the curve, an increment of environmental change results in a much greater response than if the same increment had occurred at the lower end of the curve. The population's response to the combined *effect* of two projects $(R_{1,2})$ is greater than the sum of its responses to the single-project effects $(R_1 + R_2)$. This type of combined effect is called a ***supra*-**additive cumulative effect.

Pi 2.3 illustrates a response curve in the form of a natural growth function, which has a decreasing slope as the independent variable increases in value. The population's response to the combined effect of two projects on the environment $(R_{1,2})$ is less than the sum of its responses to the single-project effects $(R_1 + R_2)$. This type of combined effect is called an ***infra*-**additive cumulative effect.

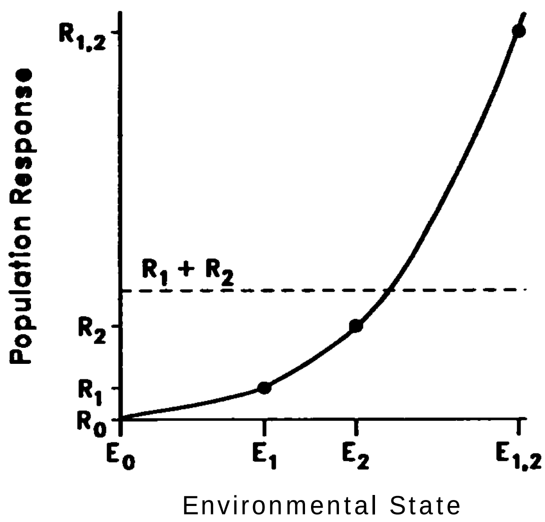

FIGURE 2.2 Example of an Exponential Response Curve ($R_1 + R_2 < R_{1,2}$)

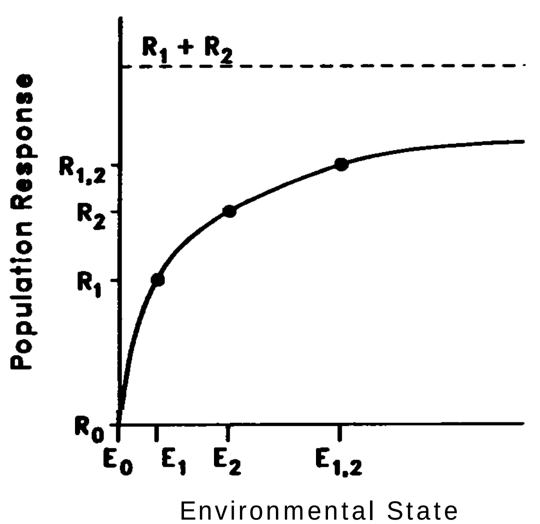

FIGURE 2.3 Example of a Natural Growth Function Response Curve ($R_1 + R_2 > R_{1,2}$)

Figure 2.4 illustrates a response curve in the form *of* a sigmoid function, which has regions of increasing slope, nearly constant slope, and decreasing slope. In this case, depending on the initial condition of the environment and the magnitude of single-project effects, the cumulative effect of two projects could be infra-additive, additive, or supra-additive.

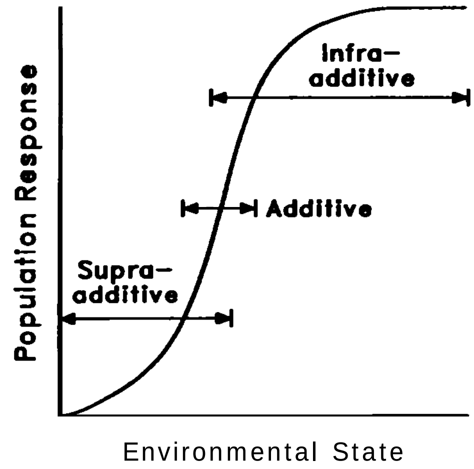

FIGURE 2.4 Example of a Sigmoid Response Curve **Showing the Possible Types** of Cumulative Effects

All of the response curves discussed above are univariate response curves, i.e., they describe the response of a species to changes in one environmental variable. In reality, species respond simultaneously to many factors in their environment, often in complex and poorly understood ways, and multivariate response curves would be required to adequately describe those responses. Multivariate response curves can incorporate interactions among variables and thus enable estimation of synergistic effects among impacts so that a more accurate estimate of cumulative effect can be obtained. However, good multivariate models are not readily available for many species, and they would have to be developed as part of the cumulative assessment process.

2.2 OVERLAPPING PROJECT IMPACT ZONES

The ITM uses response curves, including univariate and multivariate models, to estimate the departure of cumulative effects for pairwise permutations of projects from the additive condition. This method for calculating cumulative effects was developed from the concept of overlapping project impact zones. Although this concept may be too simplistic to adequately describe some hydropower effects, it provides an important foundation for cumulative effects assessment. According to this concept, each hydropower project has an impact zone, within which it can directly affect a population. Projects occurring close together may affect the same area of habitat of a species, or a species may migrate into the separate impact zones of several projects. If so, the project impact zones overlap, and it is in this area that a nonadditive cumulative effect can occur. (If no overlap occurs, the cumulative effect of several projects would simply be additive.) If the single-project impacts in the area of overlap can be identified, a response curve can be used to estimate whether the cumulative effect occurring there is supra-additive, additive, or infra-additive.

Figure 2.5 illustrates how the impact zones of two hydropower projects might overlap. This overlap can be either a large or a small fraction of the total impact zone of one or both projects. The size *of* this fraction will determine how important a response curve is in determining cumulative effects, for even a very strong nonadditive

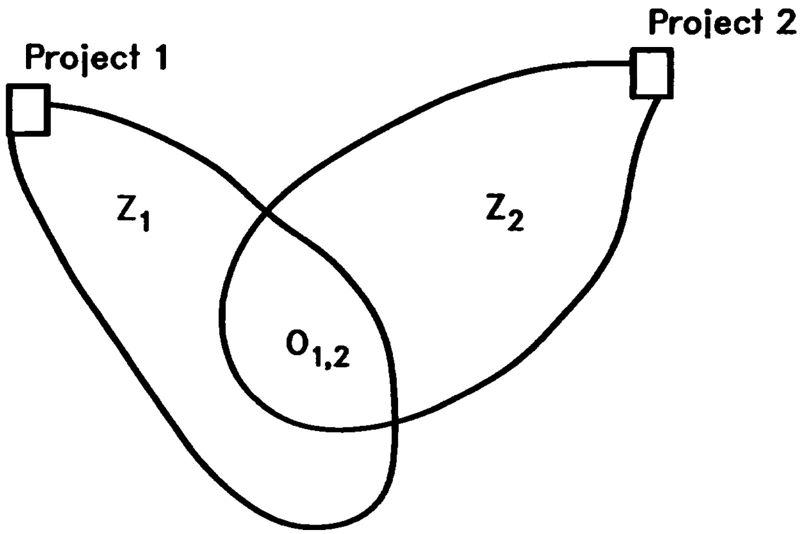

FIGURE 2.5 Example of Overlapping Project Impact Zones

response will have little influence on cumulative effects if the overlap *of* project impact zones is very small. Thus, the equation for the cumulative effects calculation must contain a term that is the ratio of the size of the *overlap* area to the size of the total project impact zone. ln Fig. 2.5, area $O_{1,2}$ is the area of overlap between project **1's** impact zone (Z_1) and project **2's** impact zone (Z_2). The fraction of Z_1 that overlaps Z_2 is equal to $O_{1,2}/Z_1$.

2.3 INTERACTION COEFFICIENTS

If a species has a nonlinear response to some environmental change, the impact of a project in the area of overlap with other projects will not be the same as the impact of that project occurring alone. The difference in impacts will be proportional to the difference between the response of the species to the environmental change caused by all projects together and the sum of its responses to the environmental change caused by each project alone. Only the responses in the overlap area are used to estimate the difference between combined-project and single-project impacts, since impacts occurring in the project impact zones outside the areas of overlap are additive.

In symbolic terms, if R indicates the response of a species to an environmental change, and the subscript **"o"** indicates responses in the areas of project impact zone overlap, then R_{1_o}, R_{2_o}, and $R_{1,2_o}$ can be defined as follows:

R_{1_o} = response of a species to the impact *of* project 1 in the area of overlap in the project 2,

R_{2_o} = response of the species to the impact of project 2 in the same overlap area, and

$R_{1,2_o}$ = response *of* the species to the combined effects of both projects in the overlap area.

The difference between the species' response to the combined-project effects and the sum of its responses to the single-project effects is therefore given by

$$R_{1,2_o} - (R_{1_o} + R_{2_o})$$

For example, suppose that, in Fig. 2.5, each project introduces some fine sediment into a stream. The area *of* deposition of fine sediment from project 1 would be Z_1 and the area of deposition of fine sediment from project 2 would be Z_2. Suppose, also, that each of the two applicants proposing the hydropower projects has estimated the effects of its project without knowledge or consideration of the other development. These are the single-project effects. Project 1 is estimated to reduce the survival of fry reared in $O_{1,2}$ **by 10%,** specifically, from 500 to 450 (a loss of 50). Project 2 is estimated to reduce the survival of fry reared in $O_{1,2}$ **by 11%,** specifically, from 500 to 447 (a loss of 53). The sum of these losses would **be** 103 juveniles, based on the single-project effects. However, suppose that experiments on fry rearing and gravel imbeddedness have shown that the losses of rearing habitat with increasing quantities of fine sediment fall into a sigmoid response pattern, as shown in Fig. 2.4. Furthermore, the experiments indicate that, at the levels of sediment expected from both projects together, the survival of fry in the overlap area should be reduced by **40%,** i.e., from 500 to 300 juveniles. Thii combined loss would be equal to 200 fish. The difference between this combined loss of fish and the sum of the single-project losses would be equal to 97 fish.

In such an example, if project 1 is constructed before project 2, then the difference is due to the ability of project 1 to modify the future impact of project 2 in the overlap area. If project 2 is constructed before project 1, then the difference is due to the ability of project 2 to modify the future impact of project 1 in the same area. However, if the order of project construction is not known, then it may not be known whether one project will modify the effects of the other or whether both will affect each other simultaneously. Use of the response curve allows one to calculate the magnitude of the combined modification of effects, but does not require knowledge of which project modifies which. In the ITM, a convention can be used of dividing the magnitude of the response modification equally between the projects, i.e., $[R_{1,2_o} - (R_{1_o} + R_{2_o})]/2$.

The ability of one project to modify the impact of another in the overlap area will have varying significance in the calculation of cumulative effects, depending on the magnitude of the single-project effect in the overlap area (R_{1_o} or R_{2_o}). A given modification of response $[R_{1,2_o} - (R_{1_o} + R_{2_o})]/2$ will be small **relative** to a **large** R_{1_o} but large relative to a small R_{1_o}. For each of two projects, this relationship **can** be expressed as:

$$\frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right)}{2 \cdot R_{1_o}} \quad \textbf{and} \quad \frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right)}{2 \cdot R_{2_o}}$$

With these quantities, one can calculate how the single-project impact of a project (I) will be changed by the influence of a species* response to environmental change in areas of project impact zone overlap. For projects 1 and 2, the single-project impacts over their entire project impact zones are I_1 and I_2, respectively. The portions of these impacts that would occur in the overlap area of their project impact zones if the projects do not interact and impacts are evenly distributed over the project impact zones are as follows (see Sec. 3.2.1):

$$I_{1_o} = I_1 \frac{O_{1,2}}{Z_1}$$
$$I_{2_o} = I_2 \frac{O_{1,2}}{Z_2} \qquad (2.1)$$

However, if the projects do interact, I_{1_o} and I_{2_o} would be modified by the degree expressed by the fractions at the end of **the previous paragraph,** i.e.,

$$I_{1_o} = I_1 \cdot \frac{O_{1,2}}{Z_1} \left[\frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right)}{2 \cdot R_{1_o}} \right]$$
$$I_{2_o} = I_2 \cdot \frac{O_{1,2}}{Z_2} \left[\frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right)}{2 \cdot R_{2_o}} \right] \qquad (2.2)$$

In these equations, the terms by which I_1 and I_2 are multiplied are referred to as ***interaction coefficients,*** which represent the adjustments needed for nonlinear effects. Symbolically, they can be designated as $C_{1,2}$ and $C_{2,1}$, respectively, i.e.,

$$C_{1,2} = \frac{O_{1,2}}{Z_1} \left[\frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right)}{2 \cdot R_{1_o}} \right]$$
$$C_{2,1} = \frac{O_{1,2}}{Z_2} \left[\frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right)}{2 \cdot R_{2_o}} \right] \qquad (2.3)$$

These coefficients determine whether the cumulative effects of two projects are additive, infra-additive, or **supra-additive.** The three cases are as follows:

- If the impacts are additive, the interaction coefficients equal 0 because $R_{1,2_o} - (R_{1_o} + R_{2_o}) = 0$,
- **If** the impacts are **supra-additive,** the interaction **coefficients** are greater than **0,** because $R_{1,2_o} - (R_{1_o} + R_{2_o}) > 0$, **and**
- If the impacts are **infra-additive,** the interaction coefficients are less than 0, because $R_{1,2_o} - (R_{1_o} + R_{2_o}) < 0$.

The cumulative impact ($I_{1,2}$) of two hydropower projects 1 and 2 (i.e., their effect over the combined area of **both** of their **impact** zones) is equivalent to

$$I_{1,2} = I_1 + I_1C_{1,2} + I_2 + I_2C_{2,1} \tag{2.4}$$

For two projects, there are only two pairwise permutations of projects. For three projects, there are six pairwise permutations, and for four projects there are twelve. For 10 projects, the number of pairwise permutations increases to 90. The equation for cumulative effects calculation becomes very complex as the number of interacting projects increases.

A convenient way to express the cumulative effects equation is with the use of matrix algebra. The matrix form of **Eq.** 2.4 for two projects is as follows:

$$\begin{bmatrix} I_1 & I_2 \end{bmatrix} \times \begin{bmatrix} 1 & C_{1,2} \\ C_{2,1} & 1 \end{bmatrix}$$

The matrix on the left is the impact matrix, the elements of which represent the single-project impacts of each project. The matrix on the right is the interaction matrix. The elements on the main diagonal of that matrix have a value of 1, and the other elements are the interaction coefficients. For instance, the element in column 2, row 1, is the interaction coefficient for project 2 in the presence of project 1.

When the matrix on the left is multiplied by the matrix on the right, the resulting matrix with two elements is

$$\begin{bmatrix} \begin{pmatrix} I_1 \\ + \\ I_2C_{2,1} \end{pmatrix} & \begin{pmatrix} I_1C_{1,2} \\ + \\ I_2 \end{pmatrix} \end{bmatrix}$$

The sum of the two elements in this product matrix is $I_1 + I_2C_{2,1} + I_1C_{1,2} + I_2$, which is the same as **Eq.** 2.4. The result, $I_{1,2}$, represents the expected **cumulative** effect of both projects over the combined area of both of their project impact zones.

The matrices for calculating the cumulative effect ***of*** three projects were shown in **Eq.** 1.1. In general, the impact matrix contains one row and as many columns as there are projects, and the interaction matrix contains as many columns and rows as there are projects. The elements ***of*** the main diagonal are always 1, and the other elements are the interaction coefficients, representing the ability of the project indicated by the column number to modify the impact of the project indicated by the row number. Matrix multiplication is further explained in Sec. 3.4.

24 SUMMARY

The ***ITM*** estimates cumulative effects by using the results of single-project impact assessment to determine the nonadditive component of cumulative effects. This nonadditive component, called the interaction coefficient, is evaluated for all of the pairwise permutations of N number of projects, using an assessment of the extent of project impact zone overlap and a curve ***or*** equation defining the response of the species to environmental change. Two matrices are multiplied: a 1 x N matrix of single-project impacts and an N x N matrix that contains main diagonal elements equal to 1 and all other elements equal to the pairwise interaction coefficients. The sum of the elements of the resultant product matrix is equal to the expected cumulative effect of all of the projects.

3 GUIDELINES FOR APPLYING THE METHODOLOGY

Cumulative effects assessment is performed in a series of six steps that result in an estimate of the impact of multiple projects acting together on a single fish or wildlife species. The six steps are:

1. Develop a conceptual and schematic description of cumulative effect,
2. Calculate the interaction coefficients,
3. Form the interaction matrix and impact matrix,
4. Multiply the matrices and sum the results,
5. Adjust for the effects of shared project features, and
6. Incorporate the effects of already existing projects into the cumulative effects assessment.

Procedural guidelines **for** each of these steps are presented below.

3.1 DEVELOPING A CONCEPTUAL AND SCHEMATIC REPRESENTATION OF CUMULATIVE EFFECT

For each impact on a species, the first step in cumulative effects assessment is to form a clear conceptual and schematic representation of how the impacts of the projects combine to affect the species of concern. This step is useful in determining where the project impact zones overlap, how they should be segmented in order to calculate the interaction coefficients, and whether the projects share such features as electrical distribution lines **or** access roads.

The main requirement of this step is to draw a map showing the affected habitats **or** populations of the species of concern. The purpose of this map is to aid in the development of the models used to calculate single- and combined-project effects. This map serves as a schematic representation of the cumulative effects problem and need not be to scale. All the features of all the projects should be placed on the map in their proper location with respect to these habitats or populations. Then, the impact zones of each project should be drawn and the areas of overlap among them identified, keeping in mind that a cumulative effects calculation may include more than one impact to a single species. These areas of overlap determine which pairs of projects will require the calculation of an interaction coefficient, should nonadditive cumulative effects be identified later in the analysis. The map will also help in identifying shared project features and in segmenting project impact zones into meaningful units. If no overlap areas occur, then the cumulative effects will be additive and no interaction coefficients need be calculated.

Since several projects may share certain features or parts of features (e.g., access roads or transmission lines), these features should also be placed on the map to help later in determining how the interaction coefficients should be calculated. It will later be necessary to identify the impacts of these features or their parts from the information provided in the single-project assessment. If it is determined that the project impact zones should be segmented, such segmentation should also be indicated on the map.

As an example, in Sec. 4.3.1, the cumulative effect of roads on elk range is calculated. The model used to calculate habitat suitability assumes that the suitability of the range changes as a function of changes in road density within contiguous portions of the range. This model is in the form of a linear equation, at least for the road densities found in the example. As a result, the cumulative effects are additive, and it is not necessary to calculate the proportion of project impact zone overlap, nor any interaction coefficients. However, as Fig. 4.1 indicates, some segments of the access roads will be used to service several projects, so a calculation of the reduction in cumulative effects due to shared project features is necessary. The access roads should be segmented into units, based on which project combinations share which road segments. These segments should be indicated on the map.

The example of effects of sediments on fish discussed in Sec. 4.3.3 is more complex. The impact zones of all projects overlap, and all of the overlap areas contain some salmon spawning habitats. Consequently, interaction coefficients for all pairwise combinations of projects should be calculated, since the response curve for fry emergence as a function of the percentage of fines is nonlinear, in the form of a decreasing sigmoid curve (see Fig. 4.6). In the example, the project impact zones are segmented into smaller units. The basis for this segmentation is twofold. First, because of the location of the projects in the basin, some reaches are affected by two projects, some by three projects, and some by all four projects. Second, according to the model used to calculate the downstream distribution of fine sediment, varying quantities of sediment are deposited at different distances from its source. Thus, the project impact zones are segmented into areas that have similar pre-impact states and experience similar impacts from construction of the projects.

Several types of project impacts may affect a single resource and these impacts must be combined in some way to determine the overall impact of the project. For example, project impacts can include sedimentation and temperature effects on fish. Because some environmental changes may interact to cause synergistic effects on the resource, multivariate models should be used to determine the combined effect of several impacts on the resource. Multivariate models can range from additive models, where the losses due to several impacts are simply added together, to complex models in which the interactions among impacts are mathematically accounted for. A simple additive model is used in the example in Sec. 5.2 to combine the impacts of passage mortality and sedimentation on chinook salmon.

3.2 CALCULATING INTERACTION COEFFICIENTS

The interaction coefficient is the quantity used to calculate the change in a project's impact caused by the influence of another project. lnteraction coefficients are calculated for all pairwise permutations *of* projects. The pairwise permutations for four projects (A, B, C, and D) are AB, BA, AC, CA, AD, DA, BC, CB, BD, DB, CD, and DC. The formula for calculating the interaction coefficient that describes the influence of one project on another is given below:

$$C_{1,2} = \frac{O_{1,2}}{Z_1}\left[\frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right)}{2 \cdot R_{1_o}}\right]$$

The terms in this equation are defined and discussed in Sec. 2.3 (see Eq. 2.3).

Before interaction coefficients can be calculated, the following steps must be taken:

1. The overlap areas of the project impact zones must be determined,
2. The project impact zones must be segmented, if necessary,
3. Shared project features must be identified, and
4. The nonlinearity of the species' responses to the combined effects of different pairs of projects must be determined.

3.2.1 Calculating tje Degree of Project overlap

The *ITM* is based on the premise that nonadditive cumulative effects are due to the modification of single-project effects when other projects are present. These modifications are thought to occur whenever the impact zones of two or more projects overlap contemporaneously within the habitat of a species. *For* example, Sec. 4 describes four proposed hydroelectric projects that produce sediment from construction of the diversion structures Since fine sediment is carried downstream, the project impact zones overlap in areas below the confluence of the streams carrying sediments from the projects. The equation for an interaction coefficient contains a term, $O_{1,2}/Z_1$, which is the ratio of the size of the overlap *of* project impact zones Z_1 and Z_2 to the size of project l's impact zone (Z_1).

Such overlap areas may be measured in several different ways. **First,** overlap may be measured as the proportion of each project area that *overlaps.* For instance, the sedimentation impacts of the Steep Creek Project in Sec. 4.3.3 extend downstream for 14 km, and those of the Rainbow Falls Project extend downstream for 10 km. Since the area of impact overlap extends for 4 km, 22% of the Steep Creek Project impact zone is overlapped by that of the Rainbow Falls Project and 40% of the latter is overlapped by the former. Measurement of project overlap bssed on areas of the impact zone should be used in cumulative effects assessment only if the following assumptions are met:

1. The species is evenly distributed throughout the impact zones,

2. The pre-impact environmental state of all areas within the impact zone is uniform, so that the response of the species to a given increment ***of*** impact is the same throughout the area, and

3. The impacting factor is evenly distributed throughout the impact zone.

In many cases, all three of these assumptions cannot be met.

A second way of measuring project overlap is to base the measurement on some unit of habitat use, thus avoiding the assumption of uniform distribution of the resource throughout the impact zone. In the example of sedimentation effects on fii a convenient unit of habitat use by fish would be the number of redds, since the impact being evaluated is the reduction of fry emergence from redds due to fines in redd sediments Concentrations of redds from salmon spawning are expected to be unevenly distributed throughout each project impact zone. In the example, the number of redds in the Steep Creek Project impact zone (reach 1 of Steep Creek and reach 1 of the Haggard River) is 121, and the number of redds in the Rainbow Falls Project impact zone (reaches 1, 2, and 3 of the Haggard River) is 266 (see Table 4.4). The number of redds within the overlap area (reach 1 of the Haggard River) is 56, so that 46% of the Steep Creek Project impact zone is overlapped by the Rainbow Falls Project impact zone, and 20% of the latter is overlapped by the former. This way of calculating project impact overlap still assumes uniformity in the pre-impact environmental state and uniformity of the impact within the impact zone. In the sedimentation example, these conditions are not met, because different reaches of the river have different pre-impact amounts of fines in the sediment, and the sediment produced by project impacts is not evenly distributed downstream.

A third way of measuring project overIap is to base the measurement on some unit of population, thus avoiding the assumption of a uniform environmental state within the impact zone. In the sedimentation example, the single-project assessment produces an estimate of the change in the number of recruits produced within the project impact zone. The number of recruits produced in different areas of the stream before project construction depends on the amount of fines in the sediments of the redds as well as the number of redds. Because some areas of the impact zone may have different amounts of fines in redd sediments, different numbers of recruits are expected to result from redds in different areas. In the sedimentation example (Table 4.4), preproject recruitments are 402 in the Steep Creek Project impact zone (reach 1 of Steep Creek and reach 1 of the Haggard River) and 1,273 for the Rainbow Falls Project impact zone (reaches 1, 2, and 3 of the Haggard River). The number of preproject recruits produced in the overlap area (reach 1 of the Haggard River) is 242, which represents 60% of the recruits from the Steep Creek Project and 19% of those ***from*** the Rainbow Fails Project. This method of calculating project impact zone overlap still assumes uniformity of the impact within the project impact zone. In the sedimentation example, these conditions are not met since sediments would be deposited unevenly downstream. These assumptions could be overcome by basing the measurement on some unit of impact, but at this stage, the distribution of impacts has yet to be calculated.

Uneven distribution of populations and impacts on populations within the project impact zones can be incorporated into the calculation of cumulative effects by project impact zone segmentation (see Sec. 3.2.2), which is a fourth method of calculating project overlap. Segmentation involves dividing the project impact zone into smaller units in which uniformity of populations and uniformity of impacts are reasonable assumptions. Table 5.5 in the sedimentation example includes estimates of the sizes of project impact zones and project impact zone overlap based on the magnitude of sedimentation impacts in impact zone segments. These estimates indicate that the Rainbow Falls project ***overlaps*** 3% of the Steep Creek Project's impacts and that the Steep Creek project overlaps 6% of the Rainbow Fall project's impacts.

Each cumulative effects assessment should include careful evaluation of whether any of the assumptions of an evenly distributed species, a uniform pre-impact environmental state, and an even distribution of impacts are met, and the conclusion reached should justify the method selected for calculating the degree of project overlap. An evaluation of these assumptions would be facilitated by a map showing the projects and their relationship to geographical and biological resources. Table 3.1 summarizes the assumptions implicit in different calculations of project overlap, and Table 3.2 illustrates the differences in estimates of project overlap that would result. These differences would have a significant effect on estimates of cumulative effect. For example, the values in Table 3.2 demonstrate that defining impact overlap areas on the

TABLE 3.1 Implicit Assumptions in the Calculation of Project Overlap Ratios

		Assumptions		
Measurement Basis	Ratio Calculated	Distribution of Population or Habitat	Distribution of Pre-Impact Environmental Conditions	Distribution of Impacts
Area size	area of overlap/ area of impact	even	even	even
Habitat	habitat in overlap/ entire habitat	uneven	even	even
Population	population in overlap/entire population	uneven	uneven	even
Impact	impact in overlap/ entire impact	uneven	uneven	uneven

TABLE 3.2 Example of Various Calculations of Project **Overlap**

Measurement Basis[a]	Example	Ratio Calculated: Steep Creek	Ratio Calculated: Rainbow Falls
Area size	impact zone overlap	0.29	0.40
Habitat	number of redds	0.46	0.20
Population	number of recruits before impacts	0.60	0.19
Impact	number of recruits lost	0.03	0.07

[a]See Table 3.1.

basis of area, habitat, or population results in an overestimate of project impact zone overlap for the Rainbow Falls and Steep Creek Projects.

The temporal distribution of impacts should also be considered when determining the degree of impact zone overlap. This is especially important for impacts that last for only a relatively short period (e.g., one or two years). For example, unless two projects are built simultaneously, the first project may no longer be producing construction-related sediment effects when the second project is built. Only contemporaneous impacts should be considered when determining the degree of impact zone overlap.

3.2.2 Determining Impact Segmentation

The example of sedimentation effects on fiih also illustrates the concept of impact segmentation. In Fig. 4.2, the streams are divided into reaches based on the environmental and biological conditions in the streams. River reaches or other areas can be subdivided into as many segments as are supported by the quantity of data available from the single-project assessments. A greater number of segments will result in a more accurate assessment of cumulative effect, but only to the extent that the variations in population distribution, pre-impact state, and impact distribution are known. To account for impact segmentation, interaction coefficients must be calculated for each segment and then summed to determine the overall interaction coefficient. This procedure uses the following formula, whereby the overlap zone of projects 1 and 2 is divided into n segments:

$$C_{1,2} = \sum_{p=1}^{n} \frac{O_{1,2_p}}{Z_1} \left[\frac{R_{1,2_{op}} - \left(R_{1_{op}} + R_{2_{op}}\right)}{2 \cdot R_{1_{op}}} \right] \qquad (3.1)$$

3.2.3 Applying Response Curves

Cumulative effects are calculated with the use of response curves that describe the impacts of environmental changes on a species. Pie 3.1 illustrates a decreasing sigmoid response curve in which additional increments of environmental change result in increasingly large increments of response by a species. The response is measured in this case as the percentage survival of juvenile salmon rearing in the streams as a function of the percentage of fines in the sediment.

As an example, assume that two projects (A and B) are proposed on streams that join some distance downstream of the projects. The project impact zones would overlap in an area of salmon rearing, so this area would receive sediment from both projects. The stream reach affected by project A is 0.8 km long, the reach affected by project B is 1.2 km long, and the length of stream in the overlap area is 0.5 km. Suppose that the juvenile survival rate in each project impact none is 20%. If only project A were constructed, fines in the sediment of its impact none would increase from 5% to 15% and the survival rate would decrease to 18%, a decrease of 2%. If only project B were constructed, the fines in the sediment of its impact zone would increase from 5% to 20%, and the juvenile survival rate would drop from 20% to 15%, a decrease of 5%. If both projects were constructed, fines in the sediments in the overlap area would increase from 5% to 30%, an increase of 25% (15% - 5% + 20% - 5%). According to the sigmoid response curve, survival of salmon juveniles at 30% fines would be 5%, which would represent a 15% decrease in survival. In contrast, if the effects of the two projects were simply additive, juvenile survival would decrease by only 7% (a 2% decrease from project A plus a 5% decrease from project B). Hence, in this example, the combined effect of the two projects in the overlap area is greater than the sum of the single-project effects; that is, a supra-additive cumulative effect would occur.

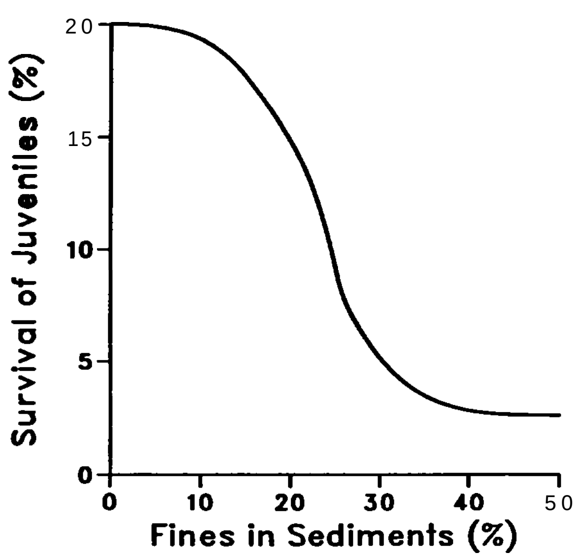

FIGURE 3.1 Hypothetical Response Curve Showing Survival of Juvenile Salmon as a Function of the Percentage of Fines in the Sediments

3.2.4 Accommodating Shared Project Features in the Interaction Coefficients

A single-project assessment should include the impacts of all project features. Rome features, such as access roads and electrical distribution lines, may be shared by several projects, and the effects of such features may be included in the single-project assessment of each project with that feature. When the effects of several projects are accumulated, the resulting estimate of cumulative effect will be too high unless some adjustment for the shared project features is ma&. In the hypothetical example presented in Rec. 4, several of the projects use the same access roads. For instance, the lower segment of the road along the Haggard River will be used for access to all four projects. Since each single-project assessment includes the effect of that access road on elk range, adding the effects of the four projects results in including the impact of that access road four times. Since the road will only occur once, three of those impacts must be removed from the cumulative *effects* estimate. Failure to identify shared project features in the first step of the cumulative effects analysis (Rec. 3.1) will result in an inaccurate estimation of cumulative effect.

The impacts of shared features should be incorporated into the interaction coefficients, *if* any project features in the area of project impact zone overlap are shared **The quantity** $R_{1,2} - (R_1 + R_2)$ contains three incidences of a shared project feature, since that feature is included separately in each term, $R_{1,2}$, R_1, and R_2 Subtracting the quantity $(R_1 + R_2)$ from $R_{1,2}$ results in the removal **of** two occurrences *of* the shared project feature when only one should be removed. To correctly calculate the interaction coefficient when a shared project feature is in the overlap area, the response of the population to the shared project feature must be added to the calculation. Then, the quantity $R_{1,2} - (R_1 + R_2)$ becomes $R_{1,2} - (R_1 + R_2) + R_{s_o}$, where R_{s_o} is the response to the shared **project** feature.

The formula for calculating the interaction coefficient then becomes

$$C_{1,2} = \frac{O_{1,2}}{Z_1}\left[\frac{R_{1,2_o} - \left(R_{1_o} + R_{2_o}\right) + R_{s_o}}{2 \cdot R_{1_o}}\right] \qquad \textbf{(3.2)}$$

Calculation of interaction coefficients for projects with shared project features and project impact zones with **n** segments should use the following **formula:**

$$C_{1,2} = \sum_{p=1}^{n} \frac{O_{1,2_p}}{Z_1}\left[\frac{R_{1,2_{op}} - \left(R_{1_{op}} + R_{2_{op}}\right) + R_{s_{op}}}{2 \cdot R_{1_{op}}}\right] \qquad \textbf{(3.3)}$$

3.2.5 Example

The best way to keep track of the terms used in calculating the interaction coefficients is to construct a table such as that shown in Pig. 3.2. In this table, the pairs of overlapping projects are identified Project 1 is defined as the project whose impacts are being modified by the impacts of another project (project **2),** because project **1's** impact zone is being overlapped by the impact zone of project 2.

Suppose that, in the example given in Sec. 3.2.3, the juveniles being reared in the project **overlap** zones come from spawning reaches that are not affected by the proposed projects. Fry emerging from **redds** move into the project overlap zones and establish residence there until they are ready to migrate downstream. Surveys of productivity in the spawning reach indicate that as many as 10,000 fry could reach the impact zone of project A. Since project A results in a change in survival from 20% to **18%,** the number of surviving juveniles could decrease from 2,000 to 1,800, a loss of 200 juveniles. The surveys also indicate that as many as 25,000 fry could reach the impact zone of project B. Since project **B** results in a change in survival from 20% to **15%,** the number of surviving juveniles could decrease from 5,000 to 3,750, a loss of 1,250 juveniles. Table 3.3 gives the values used to calculate the interaction coefficients in this example.

Project		Overlap Zone, $O_{1,2}$	Impact Zone, Z_1	Population Responses				Interaction Coefficient, $C_{2,1}$
1	2			$R_{1,2_o}$	R_{1_o}	R_{2_o}	R_{s_o}	
A	B							
A	C							
A	D							
B	A							
B	C							
B	D							
C	A							
C	B							
C	D							
D	A							
D	B							
D	C							

FIGURE 3.2 Column and Row Headings for a Table Showing the Calculation of Interaction Coefficients (for projects A, B, C, and D)

TABLE 5.3 Example of Values Used to calculate the **Interaction Coefficients for Two Projects (A and B)**

Project 1	Project 2	Zones (km) $O_{1,2}$	Zones (km) Z_1	Change in Survival (%) $R_{1,2_o}$	Change in Survival (%) R_{1_o}	Change in Survival (%) R_{2_o}	Interaction Coefficient, $C_{1,2}$
A	B	0.5	0.8	15	2	5	1.2s
B	A	0.5	1.2	15	5	2	0.33

3.3 SETTING UP THE MATRICES

Two matrices are required for a cumulative effect calculation: an impact matrix and an interaction matrix, which are then multiplied together. The impact matrix is a single row composed of the single-project impacts. In the example given in Sec. 3.2.5, the single-project impacts are $I_A = 200$ juveniles and $I_B = 1{,}250$ juveniles. Thus, the impact matrix is as follows:

$$[200 \quad 1{,}250]$$

The interaction matrix has as many rows as columns. The elements in this matrix are the interaction coefficients representing the ability of the project indicated by the column number to modify the effect of the project indicated by the row number. The diagonal elements in the matrix are always equal to 1. For the example in Sec. 3.2.5, the interaction matrix is as follows:

$$\begin{bmatrix} 1 & 1.25 \\ 0.33 & 1 \end{bmatrix}$$

3.4 MULTIPLYING THE MATRICES

The matrix multiplication for the sedimentation example in Sec. 3.2.5 is as follows:

$$[200 \quad 1{,}250] \times \begin{bmatrix} 1 & 1.25 \\ 0.33 & 1 \end{bmatrix}$$

$$= [1200(1) + 1{,}250(0.33)] \quad [200(1.25) + 1{,}250(1)]$$

$$= [612.5 \quad 1{,}500]$$

Matrices are multiplied in the following way. Element 1 of the left matrix is multiplied by element 1, column 1, of the right matrix (i.e., 200 x 1 in the example above). To that result is added the result of multiplying element 2 of the left matrix by element 2, column 1, of the right matrix (i.e., 1,250 x 0.33). This forms the first element *of* the product matrix above. Then, element 1 of the left matrix is multiplied by element 1, column 2, of the right matrix (i.e., 200 x 1.25) and added to the result of multiplying element 2 of the left matrix by element 2, column 2, of the right matrix (i.e., 1,250 x 1). This quantity forms the second element of the product matrix.

The sum of the elements in the product matrix is equal to the cumulative effect of the two projects, in this case a loss of **2,112.5** juveniles. In comparison, the sum of the single-project impacts is 200 + 1,250, which equals 1,450.

3.5 ACCOUNTING FOR SHARED PROJECT FEATURES

The *effects* of shared project features are considered in the calculation of interaction coefficients and should also be evaluated after the matrix calculation of cumulative effects (i.e., after the impact and interaction matrices are multiplied). The single-project impacts in the impact matrix will each contain the effect of any feature shared with other projects. Thus, the effect of a feature shared by two projects is added into the cumulative effects calculation twice, when that feature only makes one contribution to cumulative effect. In order to adjust for the effect of a shared project feature on cumulative effects matrix calculations, this effect should be subtracted from the sum of the elements of the product matrix. The general formula for the impact of multiple projects with n shared project features is as follows:

$$\text{Cumulative effect} = U - \sum_{i=1}^{n} I_i(S_i - 1) \quad (3.4)$$

where:

U = unadjusted cumulative *effect,* calculated as the sum of the elements in the product matrix,

I_i = impact of shared project feature i, and

S_i = number of projects sharing feature i.

3.6 INCORPORATING THE EFFECTS OF EXISTING PROJECTS

Projects that already exist in a basin may have already affected a species in that basin. For some impacts (e.g., construction effects), the species may have recovered from the impact and returned to predevelopment levels. For other impacts (e.g., sedimentation effects or passage mortality), the existing project may continue to adversely affect the species. In the second case, the existing project has effectively changed the environmental baseline (E_0 in Sec. 2.1) from that which existed before any development in the basin occurred.

In order to incorporate the effects of existing projects or ongoing activities in the cumulative assessment, these effects must be determined. If it is determined that the predevelopment levels of a species have been restored and that no further losses are expected to result from the project's continued presence or operation, the project need not be considered *further* in the cumulative assessment. If, however, it is determined that the project continues to affect the species, some assessment of these impacts must be made. This can usually be accomplished through the application of some model.

The effect of existing projects should be incorporated into the assessment of the single-project effects of each proposed project. In other words, the single-project effects should be made based on an environmental baseline that incorporates the effects of the existing project. In the example presented in Sec. 5.2.6, the survivorship of juvenile salmon to adult recruits is lower in the presence of an existing dam and this effect of the existing project is incorporated into the survivorship model for estimation of chinook salmon recruitment. In this example, impacts on chinook salmon within the hypothetical Haggard River Basin are **assessed** for only one impact of the existing project, i.e., passage mortality.

If, as suggested above, the effects of existing projects are incorporated into the new environmental baseline of proposed projects, the losses due to proposed projects will often be less than would have occurred had the existing projects never been built. *A* cumulative assessment that evaluates total **losses,** including those of existing projects, should be calculated using the following formula (modified from Eq. **3.4):**

$$\text{Cumulative effect} = U_i - \sum_{i=1}^{n} I_i(S - 1) + \sum_{j=1}^{m} I_j \qquad (3.5)$$

where:

I_j = impact of existing project j, and

m = number of existing projects that affect the resource being considered in the assessment.

4 BACKGROUND FOR THE HYPOTHETICAL EXAMPLE

Thii section presents a hypothetical example of hydroelectric development in order to demonstrate the use of the lTM for cumulative effects assessment. The example involves the construction of four hydroelectric power-generating facilities. The following project impacts are considered: the impacts of passage mortality and sedimentation on chinook salmon recruitment, and the impact of disturbance on elk in their winter and summer ranges. This section provides background data for the hypothetical example and the results, in terms of these specific impacts, of single-project assessments for each of the. ***four*** projects. In Sec. 5, these results are used to complete a cumulative effects assessment with the **ITM,** according to the procedural guidelines described in Sec. 3.

4.1 PROJECT FEATURES

The facilities are located on a nonexistent river basin, the Haggard River Basin, which could be a tributary of a major river such as the Columbia River (Fig. 4.1). To facilitate discussion, each project has been given a name; however, these hypothetical projects are not meant to be similar to any existing or proposed projects that may have the same names. The features of each project are summarized in Table 4.1. Reference in the example is also made to the Columbia River Project, an existing, but hypothetical, hydroelectric facility that is located on the Columbia River 80 km downstream of the confluence between the Haggard and Columbia Rivers. Appendix B provides a more thorough description of each proposed project and the existing Columbia River Project.

4.2 EXISTING ENVIRONMENT

4.2.1 stream **Characteristics**

Flow regimes in the Haggard River Basin are typical of Rocky Mountain streams and are dominated by input from snow melt. Thus, the highest stream flows occur in May through July, while lower (and generally uniform) flows occur in August through April (Table 4.2).

The streams are located within forested watersheds underlain by a granitic batholith. Dominant soils consist of a 0- to 7.8-cm-thick organic layer over a 50- to 150-cm-thick layer of gravelly sand that consists of up to 25% fine gravels. The soil is underlain by moderately to well-weathered granite (Cline et al. 1981).

The physical characteristics ***of*** the streams are presented in Table 4.3. Each stream has been subdivided into one or more reaches (Fig. 4.2) that differs in physical characteristics such as gradient, depth, width, and **substrate** composition.

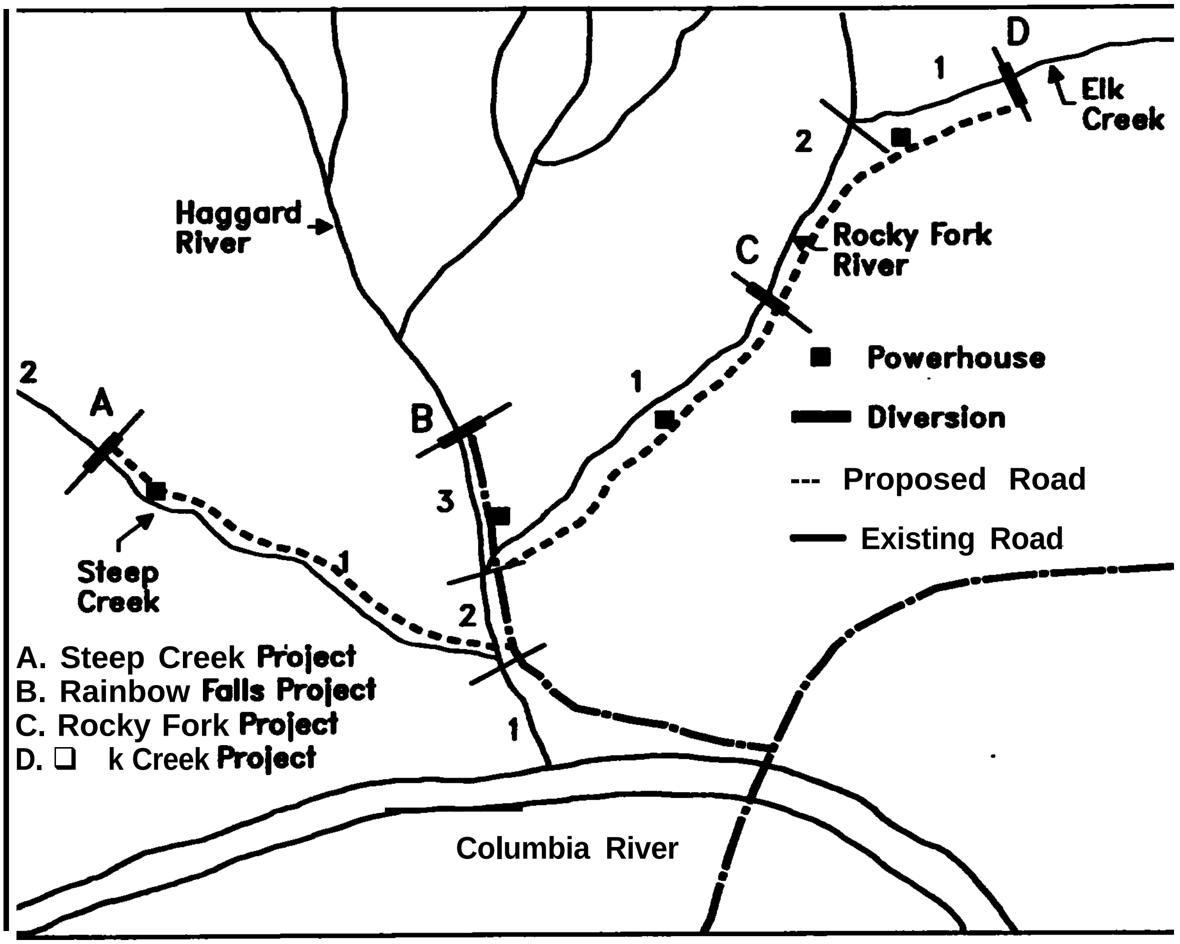

FIGURE **4.1 Hypothetical** Example of **Proposed Hydroelectric** Development in **the Haggard River Basin**

TABLE 4.1 Proposed Projects in the Hypothetical Example: Features and Letter Designations

Name of the Proposed Project	Letter Assigned	Diversion Structure **(m)**		**Penstock Length (km)**	**New** Access **Road (km)**	Generating Capacity **(kW)**
		Height	Width			
Steep Creek	A	1	12	1.5	9.4	352
Rainbow Falls	**B**	11	**85**	3.3	0	14,840
Rocky fork	**C**	1	8	5.4	10.4	430
Elk Creek	**D**	1	**5**	2.8	14.6	263

TABLE 4.2 Mean Monthly Discharges at Project Locations (cfs)

Month	Steep Creek	Haggard River	Rocky Fork River	Elk Creek
January	23.3	222.9	8.1	4.8
February	11.8	112.9	5.4	3.2
March	8.8	84.2	4.8	2.8
April	35.9	343.5	9.7	5.7
May	81.5	779.8	35.0	20.8
June	226.1	2,546.2	90.2	53.6
July	137.1	1,311.8	31.4	18.6
August	39.4	377.0	8.4	5.0
September	39.4	377.0	6.4	3.8
October	16.7	159.8	5.7	3.4
November	25.9	247.8	8.4	5.0
December	21.7	207.6	6.8	4.0
Average	59.0	564.2	18.3	10.9

TABLE 4.3 Physical Characteristics of Project Streams

Stream	Reach[a]	Length (km)	Drainage Area (km^2)	Gradient (%)	Sediment Load (tons/yr)	Routing Coefficient[b]	Fines in Sediment (%)
Steep Creek	1	10.0	81.6	1.2	791.5	0.54	32.2
Haggard River	3	3.3	150.0	5.1	5,790.0	0.48	16.6
	2	2.7	240.0	4.3	9,264.0	0.44	18.5
	1	4.0	350.0	3.7	13,510.0	0.41	20.1
Rocky Fork River	2	1.2	21.2	3.6	205.6	0.68	20.4
	1	10.4	174.0	2.5	1,350.0	0.47	24.3
Elk Creek	1	3.0	9.7	9.9	94.1	0.79	9.5

[a]Stream reaches are identified in Fig. 4.2.

[b]The proportion of sediment that moves downstream to the next reach (see Sec. 4.3.3).

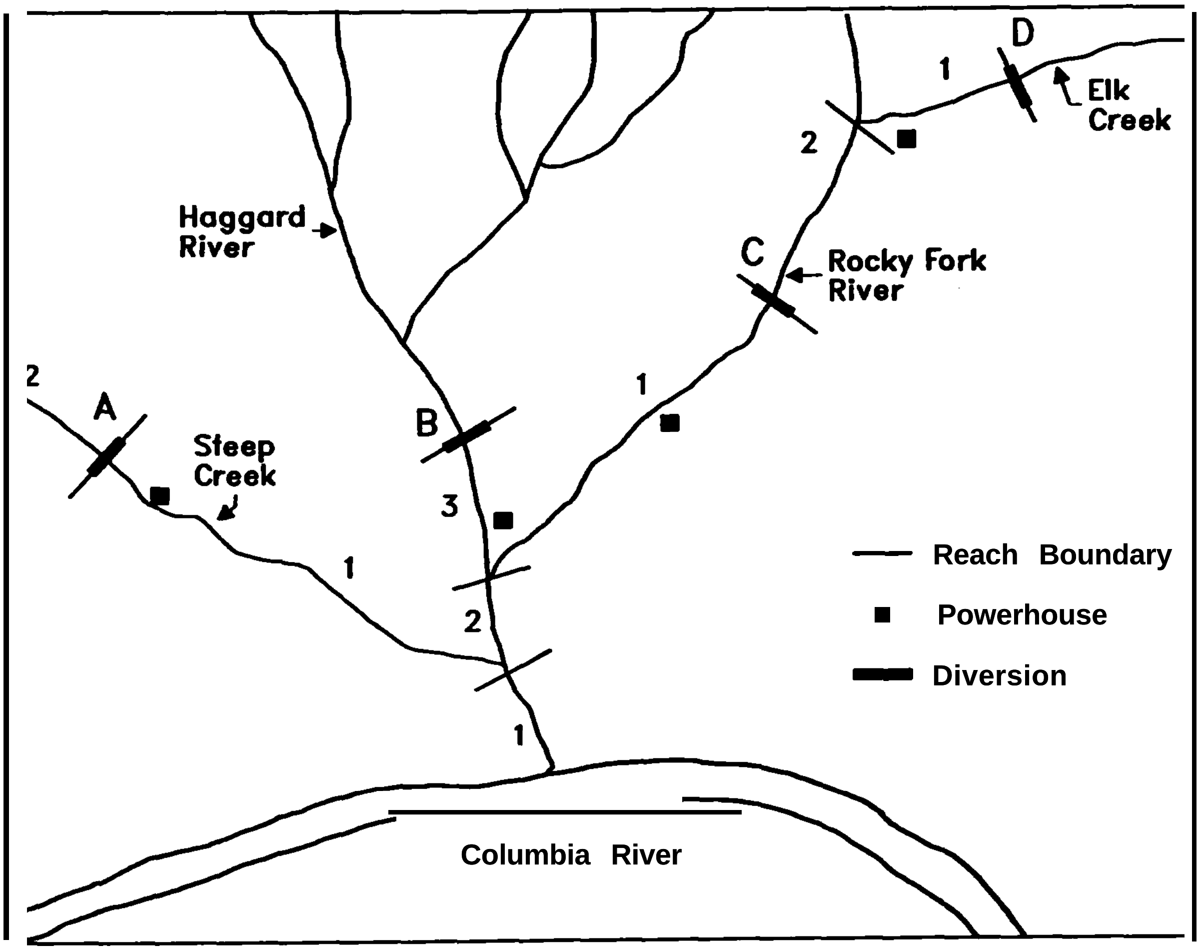

FIGURE 4.2 stream Reaches Considered in the Haggard River Basin

4.2.2 Species Characteristics

Chinook salmon **(*Oncorhynchus tshawytscha*)** and elk **(*Cervus elaphus*)** were chosen as the fish and wildlife species to be included in this demonstration of cumulative impact analysis. These species were selected because their migratory habits make them susceptible to cumulative impacts and because they both occur in habitats where clusters of small-scale hydroelectric projects are often proposed.

4.2.2.1 Elk

Elk occupy a variety of habitats in the western United States. In mountainous regions, elk sometimes migrate considerable distances (up to 90 km) between summer and winter ranges (Peek 1982). Snowfall strongly influences the location of the winter range. Elk prefer areas where snowfall is moderate and does not restrict movement and foraging. As snow cover diminishes in the spring, elk *begin* to move to summer range at higher elevations and frequently migrate up stream valleys.

Elk are often affected by hydroelectric development because *of* their preference for riparian and other habitats near streams. Population impacts generally result from habitat loss due to inundation, the construction of project facilities and associated disturbance, and the continuing disturbance from maintenance activities and increased general use of the area.

Elk occur in the Haggard River Basin at moderate densities. Pellet group surveys have indicated that the upper Steep Creek drainage and the upper Rocky Fork River drainage are used as summer range by herds consisting of 32 and 24 elk, respectively. The habitat within the areas used as summer range consists of alpine meadows, mixed coniferous *forests* of fir and spruce, and early seral habitats in areas where wildfires occurred within the last 10 years. Both herds (totaling 58 elk) winter in the lower reaches of the Haggard River (Fig. 4.3). Much of this habitat is old-growth Douglas fir with adequate browse in the understory.

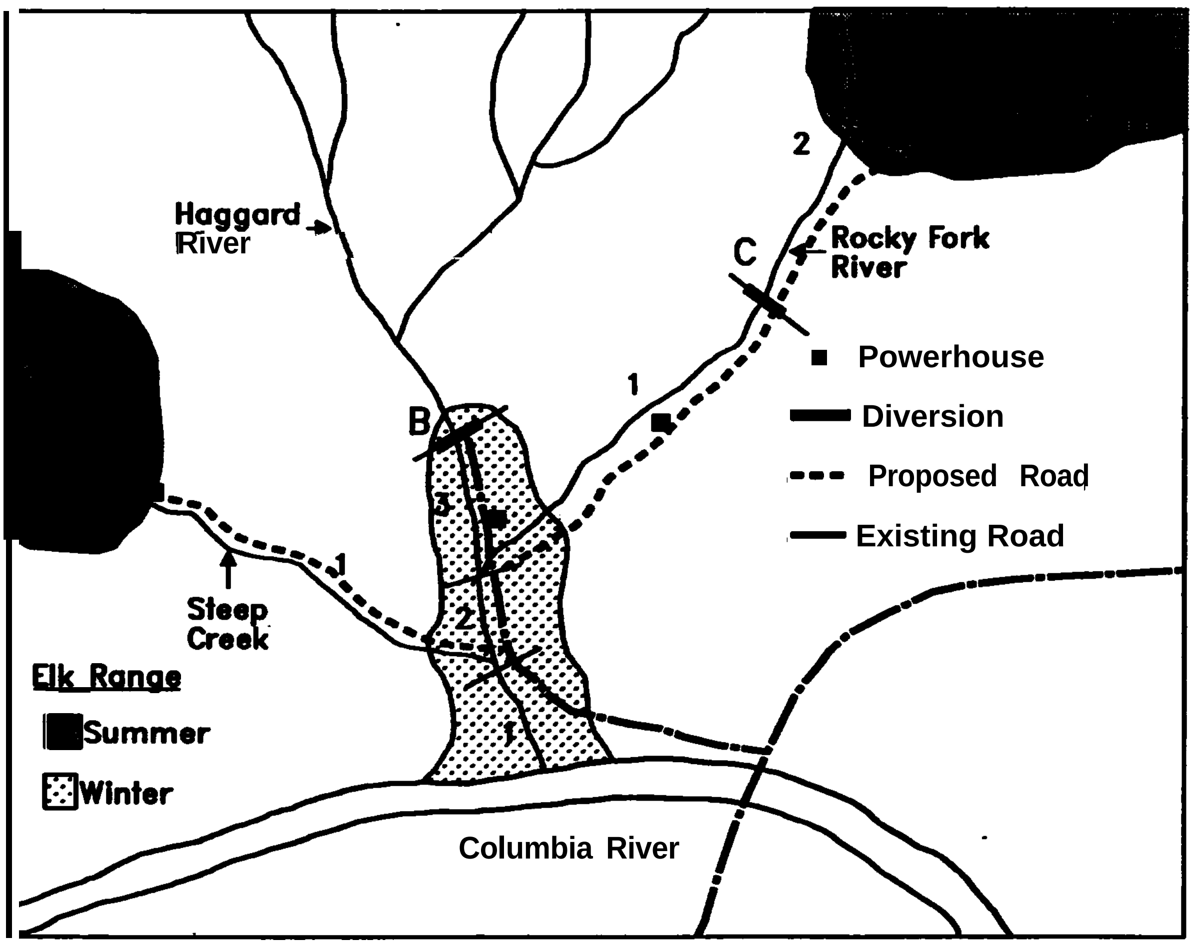

FIGURE 4.3 Elk Habitats in the Haggard River Basin

4.2.2.2 Chinook Salmon

The chinook salmon spawns in large rivers or large tributary streams and requires gravel substrates generally free of fine sediments for spawning. Hydroelectric facility construction and operation can affect chinook salmon in a number of ways, but only two effects -- sedimentation *effects* on emergence and passage mortality -- were considered in this example. The measurement basis selected for both effects was a population measure, i.e., the number of recruits lost as a result *of* these effects= Sediment from project construction often travels a considerable distance downstream from the construction area, adds to the sediment load of reaches affected by other projects in the same basin, and therefore has the potential to cause cumulative impacts. Demonstrated effects of sediment on emergence rates are also available. Passage mortality was also considered to be a potentially cumulative effect because migratory juvenile and adult fish often have to pass a number of hydroelectric facilities. Mortality that occurs during juvenile and adult passage of each facility contributes to overall recruitment loss.

ln the example, a race of spring chinook spawns in various reaches of the project streams (Fig. 4.4), and the estimated numbers of redds in reaches below the proposed diversions are **specified** in Table 4.4. The chinook salmon migrate upstream from July to mid-October and spawn from mid-August to late November. The eggs develop during the period of mid-August to late February, and juveniles emerge from the gravel between mid-January and early ***March.*** Juvenile outmigration occurs from mid-April to June of the year following emergence (Pacific Northwest River Basins Commission 1970, Everest and Chapman 1972). ***A*** natural falls located near river kilometer (RK) 10 on the Haggard River prevents any further upstream migration of the salmon.

In ***order*** to assess the effects of sedimentation and passage mortality from hydropower construction and operation on the number of chinook salmon recruits, several assumptions were made concerning chinook salmon life history data. The **average** number of eggs per redd (3,000) was conservatively derived from a range of values given in Vronskii (1972), Scott and Crossman (1973), and Hart (1973). The percentage of fry emergence from redds was based on the percentage composition *of* fines within each stream reach, following the formula of Stowell et al. (1983) given in Sec. 4.3.3 (see Eq. 4.5). Estimated values for the percentages of fry emergence in stream reaches where spawning occurs are presented in Table 4.4. Assumptions were then made on natural survival rates for subsequent life phases, partially based on rates developed by the Northwest Power Planning Council (1986). The rates used were as **follows:**

- For juveniles: 12.8% survival before migration, 98% survival in the Columbia River Reservoir, 85% survival in passage of the Columbia River Dam, 85% survival from the dam to the estuary, and 5% survival from the estuary to the ocean; and

- For adults: 60% survival in the ocean, 78% survival in travel to the dam, and 90% survival in upstream passage of the existing dam.

The overall survivorship rate from juvenile to spawning recruit, therefore, was 0.184%. From this information, the estimated number of recruits originating from each stream reach (Table 4.4) was calculated using the following formula:

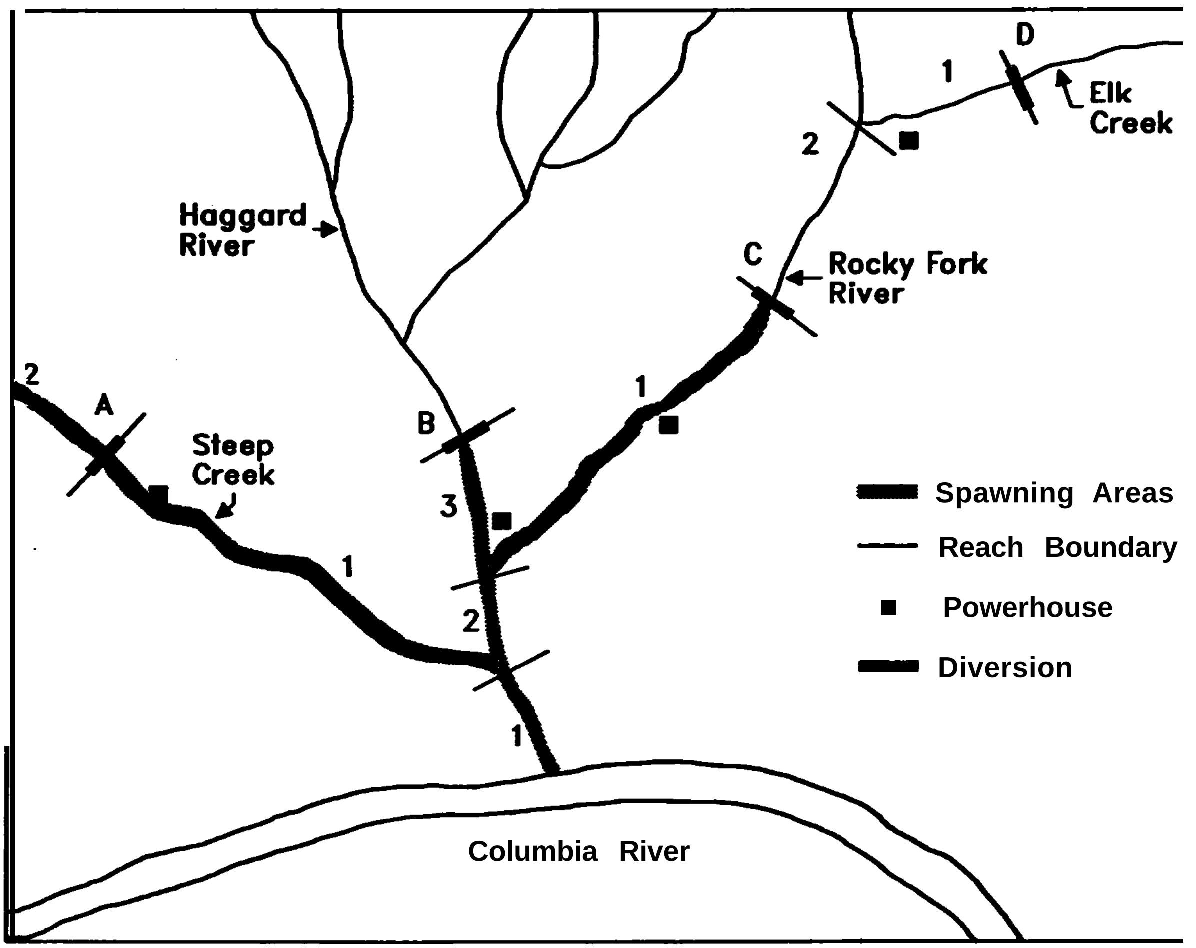

FIGURE 4.4 Spawning Areas of Chinook Salmon in the Haggard River Basin

$$\text{Recruits} = 5.52RE \tag{4.1}$$

where:

5.52 = a constant derived from the number of eggs per redd (3,000) and the survivorship of juveniles to recruits (0.184%),

R = number of redds, and

E = percentage of fry emergence (calculated from the existing percentage of fines in the substrate).

TABLE 4.4 **Preproject Levels of Chinook Salmon Redds, Fry Emergence, and Recruitment**

stream	Reach	Ho. of **Redds**	Fry **Emer-gence (%)**	Ho. of **Recruits**
Steep Creek	2	11	84.7	51
	1	65	44.5	160
Haggard River	3	36	83.3	166
	2	194	80.8	865
	1	56	78.1	242
Rocky Fork River	2	0	0	0
	1	43	68.9	164
Elk Creek	1	0	0	0
Total		405		1,648

4.3 SINGLE-PROJECT IMPACTS

4.3.1 Loss of Elk Due to Disturbance

Elk are very susceptible to disturbance by humans. Improved access is a major cause of increased human use of an area, and elk generally avoid habitats that are crossed by roads that receive even light use (Lyon 1983, U.S. Forest Service 1985, Wisdom et al. 1988). The decline in habitat suitability (also referred to as habitat effectiveness) that results from the development of roads has been described by the following functions (Wisdom et al. 1986):

$$\text{If } ED < 0.62,\ HS = 1 - (0.64)(RD) \tag{4.2}$$

$$\text{If } RD > 0.62,\ HS = 0.7 - (0.20)(RD) \tag{4.3}$$

where:

RD = road density (km/km^2 of elk range), and

HS = habitat suitability.

The relationship between habitat suitability and road density is depicted in Fig. 4.5.

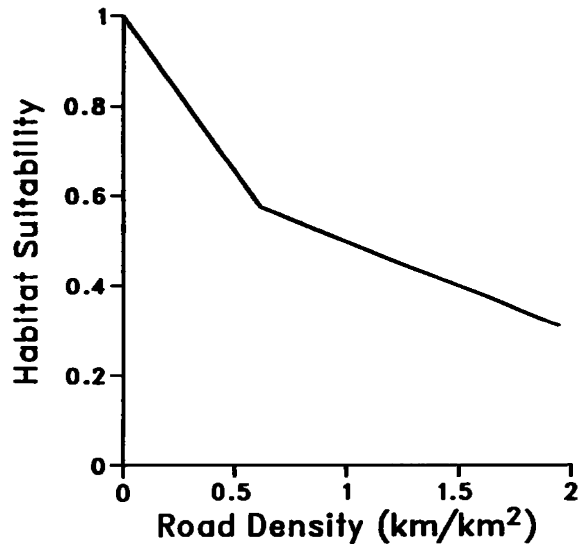

FIGURE 4.5 Effect of Road Density on Elk Habitat Suitability (Source: Wisdom et al. 1999)

Habitat suitability, as calculated here, is the value between 0 and 1 that describes the suitability of the habitat to elk relative to an equivalent habitat without any roads. Thus, if the construction of roads in a roadless area results in a habitat suitability value of **0.75,** the suitability of the area after road construction is only 75% of its former value. The habitat suitability of the entire range is assumed to be affected by the development of any road within that range.

The length of road required for each project is presented in Table 4.1, and the location of all project roads in relationship to the projects is presented in Fig. 4.1. Development of any of the projects would result in increased public recreational use of the existing access road (12 km long) along the Haggard River. This road is currently under restricted access and is used infrequently each year for stocking purposes only. ***Therefore,*** in the assessment ***of*** project effects on elk disturbance, the opening ***of*** this road was considered equivalent to building a new road. Road densities were calculated for occupied elk summer and winter ranges. ***A*** reduction in habitat suitability due to road construction and use was assumed to cause a proportionate reduction in the number of elk using the ***affected*** range. The effect ***of*** each project on habitat suitability and elk numbers is presented in Table 4.5.

4.3.2 Reduction in Chinook Salmon Recruitment Due to Passage Mortality

Since hydroelectric facilities can completely block the upstream migration of adults, thus eliminating spawning above the dam, such facilities generally incorporate anadromous fiih passage structures. Nevertheless, migrating fii are still subject to mortality risks during passage. Adults **risk** mortality as they move through passage structures during upstream migration. Juveniles risk mortality as they move downstream through reservoirs because they may become disoriented within the reservoir and be delayed in passage through it, be affected by adverse temparatures and oxygen concentrations in the reservoir, and experience increased predation (Ward and Stanford 1979). Turbine passage, impingement, injury from passage over diversions, and increased predation risk also contribute significantly to downstream passage mortality rates. Passage mortality rates are generally less at small hydroelectric facilities than at large mainstem river facilities.

TABLE 4.5 Effects of Single Projects on Habitat Suitability and Elk Numbers

Range Affected, Project	Road Density (km/km^2)	Habitat Suitability	Number of Elk Lost
Summer range			
Steep Creek	0.104	0.93	2.1
Rainbow Falls	0	1.00	0
Rocky Fork	0	1.00	0
Elk Creek	0.156	0.90	2.4
Winter range			
Steep Creek	0.139	0.91	5.0
Rainbow Falls	0.179	0.89	6.S
Rocky Fork	0.164	0.90	5.9
Elk Creek	0.164	0.90	5.9

Chinook salmon in the Haggard River Basin would be subject to passage mortality at the proposed Steep Creek diversion and at the existing Columbia River Project. The latter project, built in 1964, is located 80 km downstream of the confluence of the Haggard and Columbia Rivers. A 10% mortality rate has been determined for adults during upstream passage of the Columbia River Project dam. Due to the low height (1 m) of the proposed diversion on Steep Creek, no measurable mortality of adults during upstream passage of the diversion is expected. Mortality of juveniles also occurs at the Columbia River Project and would occur at the Steep Creek Project due to downstream passage of the project facilities. A 15% mortality rate was estimated for outmigrating juveniles passing the Columbia River Project dam, and a 4% mortality rate was determined for passage through the Columbia River Project reservoir (Northwest Power Planning Council 1988). A 10% mortality rate is expected for juveniles passing the Steep Creek diversion.

The impact on recruitment due to passage-related mortality at the existing Columbia River Project was incorporated into the overall survival rate given in Sec. 4.2.2.2. As a result of passage mortality at this facility, only 1,848 recruits are estimated to enter the Haggard River watershed for spawning on an annual basis. In contrast, 2,244 recruits would be expected to enter the system if the mainstem Columbia River Project were not present.

4.3.3 Reduction in chinook Salmon Recruitment Due to the Effects of Sedimentation on Emergence

Development-related sediment input to the streams is expected to result primarily from road construction (and subsequent erosional runoff from traffic and storms) and from instream construction of diversion structures.

Sediment yield to nearby streams from road surface erosion was estimated to average 74.13 tons/km-yr over the initial 5 years following construction (Cline et al. 1981). Only part of this sediment, however, would remain within each reach, because sediment is transported downstream. The proportion of sediment passing out of a given reach to the next reach downstream was determined by calculating a routing coefficient using the following formula (Cline et al. 1981):

$$RC = 1.187X^{-0.18} \quad (4.4)$$

where:

RC = routing coefficient, and

X = upstream drainage area (km^2).

Routing coefficients for the stream reaches in the example were presented in Table 4.3.

The amount of sediment in a given reach depends not only on the routing coefficient for that reach, but also on the amount of new sediment moving into the reach from upstream reaches. The following formula yield8 the approximate amount of sediment in a given reach at equilibrium:

$$\text{Sediment} = (1 - RC)(74.13L + S_{up}RC_{up}) \quad (4.5)$$

where:

74.13 = amount of sediment eroded annually from a 7.6-m-wide road (Cline et al. 1981) during the first 5 years after construction (tons/km),

L = length of road (km) in the reach of concern,

RC = routing coefficient for the reach of concern,

RC_{up} = routing coefficient for the upstream reach, and

S_{up} = sediment transported or eroded into the upstream reach.

Where appropriate, instream sediment inputs from construction of the diversions were added. This additional input was assumed to be 180 tons/yr for the first 5 years following construction of the Rainbow Falls Project and 40 tons/yr for each of the other projects.

The percentage of fines in the substrate following hydroelectric development was next calculated using the formula of Leathe and Enk (1985):

$$\% \text{ Fines} = 34.18 + 0.55X_1 - 24.80X_2 \quad (4.6)$$

where:

X_1 = percentage increase in sediment over natural amounts, and

$X_2 = \log_{10}$ stream gradient.

From this information, the percentage emergence of fry from redds was calculated using the formula of Stowell et al. (1983):

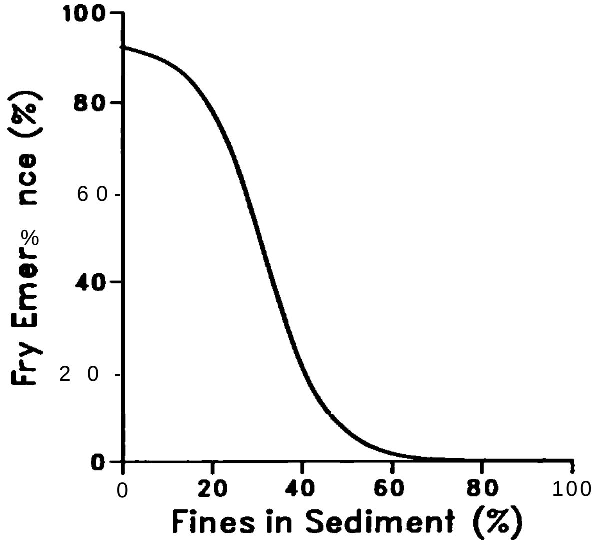

FIGURE 4.6 Effect of the Fines in Sediment on Chinook Salmon Fry Emergence (Source: Stowell et al. 1981)

$$\% \text{ Emergence} = \frac{92.95}{1 + e^{(-4.559 + 0.1442F)}} \quad (4.7)$$

where F equals the percentage of fines in the sediment. The relationship between emergence and fines is represented in Fig. 4.6.

The number of recruits lost after hydroelectric development was determined by substituting the predicted percentage emergence into Eq. 4.1. Table 4.6 presents the effects of each of the four projects on all of the stream reaches considered, in terms of sediment load, the percentage of fines, and chinook salmon emergence and recruitment.

TABLE 4.6 **Effects of Each Project on Chinook Salmon Recruitment**

Project	Stream	Reach	Sediment Increase (tons/yr)	Increase in % Fines	Decrease in % Emergence	Recruits Lost Total[a]	Recruits Lost %
Steep Creek	Steep Creek	2	0	0	0	5.2[b]	
		1	344	23.9	41.8	150.1	
	Haggard River	3	0	0	0	0	
		2	0	0	0	0	
		1	235	1	1.8	5.6	
	Rocky Fork River	2[c]	0	0	0	0	
		1	0	0	0	0	
	Elk Creek	1[c]	0	0	0	0	
	Total					160.8	9.8
Rainbow Falls	Steep Creek	2	0	0	0	0	
		1	0	0	0	0	
	Haggard giver	3	93	0.9	1.2	2.3	
		2	48	0.3	0.4	4.8	
		1	23	0.1	0.2	0.5	
	Rocky Fork River	2[c]	0	0	0	0	
		1	0	0	0	0	
	Elk Creek	1[c]	0	0	0	0	
	Total					7.6	0.5
Rocky Fork River	Steep Creek	2	0	0	0	0	
		1	0	0	0	0	
	Haggard giver	3	0	0	0	0	
		2	212	1.3	2	21.9	
		1	99	0.4	0.7	2.3	
	Rocky Fork River	2[c]	0	0	0	0	
		1	431	17.6	51.6	122.6	
	Elk Creek	1[c]	0	0	0	0	
	Total					146.8	8.9
Elk Creek	Steep Creek	2	0	0	0	0	
		1	0	0	0	0	
	Haggard River	3	0	0	0	0	
		2	255	1.5	2.5	26.7	
		1	119	0.5	0.9	2.7	
	Rocky Fork giver	2[c]	93	24.9	0	0	
		1	517	21.1	57.7	136.9	
	Elk Creek	1[c]	56	32.5	0	0	
	Total					166.3	10.1

[a]Losses due to sedimentation effects on emergences rates in all reaches except where noted othervise.

[b]Losses due to a 10% decrease in survivorship of juveniles as they pass the diversion (see Sec. 4.3.2).

[c]No redds were found in this reach during preconstruction surveys.

5 CUMULATIVE EFFECT ASSESSMENT USING THE HYPOTHETICAL EXAMPLE

This section continues with the hypothetical example introduced in Sec. 4. The single-project assessment results derived in that section are combined below into a cumulative effect estimate in accordance with the steps outlined in Sec. 3. As before, the assessment is restricted to impacts on (1) elk summer and winter range and (2) chinook salmon recruitment.

5.1 LOSS OF ELK DUE TO DISTURBANCE ON SUMMER AND WINTER RANGE

5.1.1 Summary of Single-Project Assessment Results

The road construction associated with the development of the four projects would result in the disturbance of two elk herds on their summer and winter range, as discussed in Sec. 4.3.1. Road construction is expected to cause a decrease in habitat suitability for elk, and a proportional reduction in elk numbers is assumed to occur. The effect of disturbance on habitat suitability and elk numbers for single projects was assessed in Sec. 4.3.1, and the results are summarized in Table 5.1.

5.1.2 Conceptual and Schematic Representation

The four projects would require access roads that pass through the winter range used by two elk herds (Fig. 5.1). In addition, the Steep Creek and Elk Creek Projects would require access roads that pass through summer ranges. Only the length of road that passes through an elk range would affect its habitat suitability for elk because habitat suitability is a function of road density in the range. The impact zones of all projects overlap in the winter range; no overlap occurs in the summer ranges. No segmentation of the overlap area was done for this assessment because elk are assumed to use all parts of the winter range equally. Some segments of access roads would be shared because of the proximity of projects to one another. The sharing of roads would result in a cumulative impact value that is less than the sum of single-project impacts. Project roads were divided into shared and unshared segments and the length of each segment in winter range was determined (Fig. 5.1). The impact of each road segment is presented in Table 5.2.

TABLE 5.1 Estimated Losses of Elk Due to Single-Project Effects

Project	No. of Elk Lost
Steep Creek	7.1
Rainbow Falls	6.5
Rocky Fork	5.9
Elk Creek	8.3

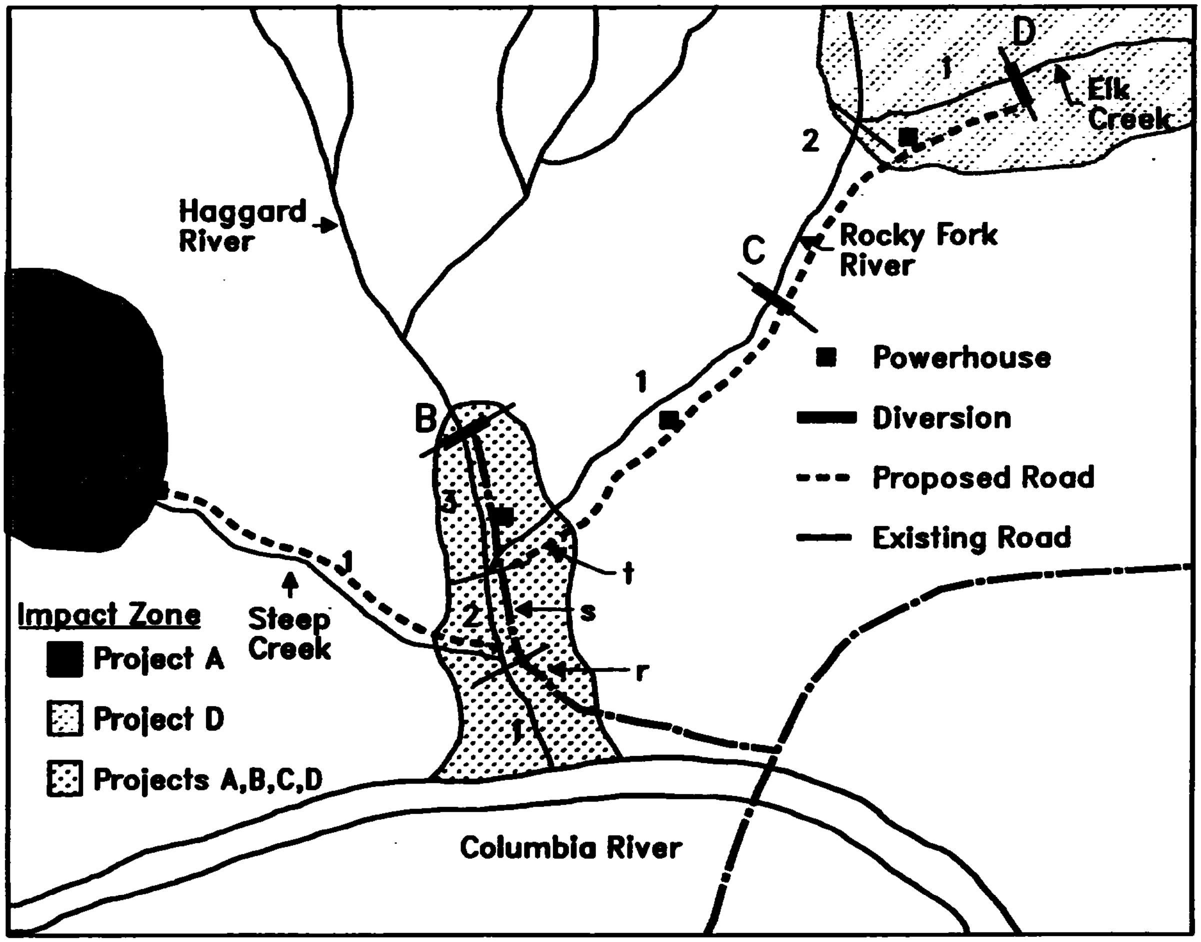

FIGURE 5.1 Project Impact Zones for Impacts on Elk Summer and Winter Range (letters r, s, and t represent segments of road that are shared by projects and affect winter range; note that all projects affect the entire winter range)

TABLE 5.2 Impact of Shared Road Segments on Habitat Suitability and Elk Numbers in Winter Range

Road Segment	Road Length in Range (km)	Road Density (km/km^2 of range)	Habitat Suitability	No. of Elk Lost	Projects Using Segment
r	2.5	0.08	0.95	2.8	A,B,C,D
s	1.0	0.03	0.98	1.1	B,C,D
t	1.8	0.06	0.96	2.0	C,D

No interactions would occur among the projects other than the sharing of project features because in the area of impact zone overlap, the road density would equal 0.3 km/km^2, which is in the range of the linear response curve described by Eq. 4.2. If the addition of a project brought total road density over the value of 0.62 km/km^2 (see Eq. 4.3), the incremental effect of the additional project would be infra-additive and interaction coefficients would have to be calculated.

5.1.3 Interaction Coefficients

As stated above, no interaction occurs among the projects other than the sharing of project features. Thus, the pairwise interaction coefficients are zero and the interaction matrix is an identity matrix (with 1's along the main diagonal, 0's elsewhere).

5.1.4 Impact and Interaction Matrices and Matrix Multiplication

The elements of the impact matrix are simply the numbers of elk lost due to the development of single projects (see Table 5.1). As discussed in Sec. 5.1.3, the interaction matrix is an identity matrix. The product matrix is the same as the original impact matrix and the sum of the elements in this matrix (27.8) is the sum of the effect of all four projects, unadjusted for shared roads.

Impact Matrix		Interaction Matrix		Product Matrix

$$[7.1 \quad 6.5 \quad 5.9 \quad 8.3] \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = [7.1 \quad 6.5 \quad 5.9 \quad 8.3]$$

5.1.5 Shared Project Features

The sum of the single-project effects in this example contains the impact of shared road segments several times. For example, road segment s is shared by three projects (Rainbow Falls, Rocky Fork, and Elk Creek). The impact of this road segment, therefore, is included in the impacts of these three projects and results in the sum being too large. The sum can be adjusted for overrepresentation of shared features by substituting the values presented in Table 5.2 into Eq. 3.4:

$$\begin{aligned} \text{Cumulative effect} &= 27.8 - I_r(4 - 1) - I_s(3 - 1) - I_t(2 - 1) \\ &= 27.8 - [2.8(3)] - [1.1(2)] - [2.0(1)] \\ &= 27.8 - 8.4 - 2.2 - 2.0 \\ &= 15.2. \end{aligned}$$

Approximately 15 elk are expected to be lost on summer and winter range due to completion of the four proposed projects.

5.2 REDUCTION IN CHINOOK SALMON RECRUITMENT DDE TO DAM PASSAGE MORTALITY AND SEDIMENTATION EFFECTS ON EMERGENCE

5.2.1 Summary of Single-Project Assessment Results

Construction of the four proposed projects would cause an increase in sediment inputs to streams through road surface erosion and instream construction of diversion structures. The impacts on salmon emergence and recruitment from increases in stream sedimentation were assessed using the modeling approach outlined in Sec. 4.3.3. The decrease in the percentage of fry emergence due to sedimentation was predicted from the estimated increase in the percentage of fines in the substrate (Stowell et al. 1983), and the number of recruits lost was calculated from the proportional reduction in emergence. Because stream reaches differ considerably in physical characteristics and salmon use, assessments were made for each stream reach rather than for each stream as a whole. In addition, the impact on juvenile mortality at the diversion at the Steep Creek Project was assessed using the approach described in Sec. 4.3.2. The results of the single-project assessments are summarized in Table 5.3.

TABLE 5.3 **Estimated Loss of Salmon Recruits Due to Single-Project Effects**[a]

Stream	Reach	Project: Steep Creek	Rainbow Falls	Rocky Fork	Elk Creek
Steep Creek	2[b]	5.2	0	0	0
	1	150.1	0	0	0
Haggard River	3	0	2.3	0	0
	2	0	4.8	21.9	26.7
	1	5.6	0.5	2.3	2.7
Rocky Fork River	2	0	0	0	0
	1	0	0	122.6	136.9
Elk Creek	1	0	0	0	0
Total		160.8	7.6	146.8	166.3

[a]Losses due to sedimentation effects on emergence rates in all reaches except where noted otherwise.

[b]Loss due to juvenile mortality at the diversion.

5.2.2 Conceptual and Schematic Representation

The impact zone of each project would include all areas in the Haggard River Basin downstream of the project because some portion of the sediment attributed to each project would travel to the confluence with the Columbia River (Fig. 5.2). In addition, the area upstream of the proposed Steep Creek diversion would be included in the impact zone of this project because of passage mortality. The projects under consideration would interact because they would contribute sediment to some of the same stream reaches. As discussed in Sec. 4.2, stream reaches differ considerably in physical characteristics and salmon populations; thus, segmentation of the overlap areas, based on these reaches, is necessary to assess cumulative effects. Also, because each reach has different characteristic redd numbers and substrate compositions (and subsequently different emergence rates), the measure of project overlap for each project was calculated as the ratio of impact in the area of overlap to the total project impact (see Sec. 3.2.1).

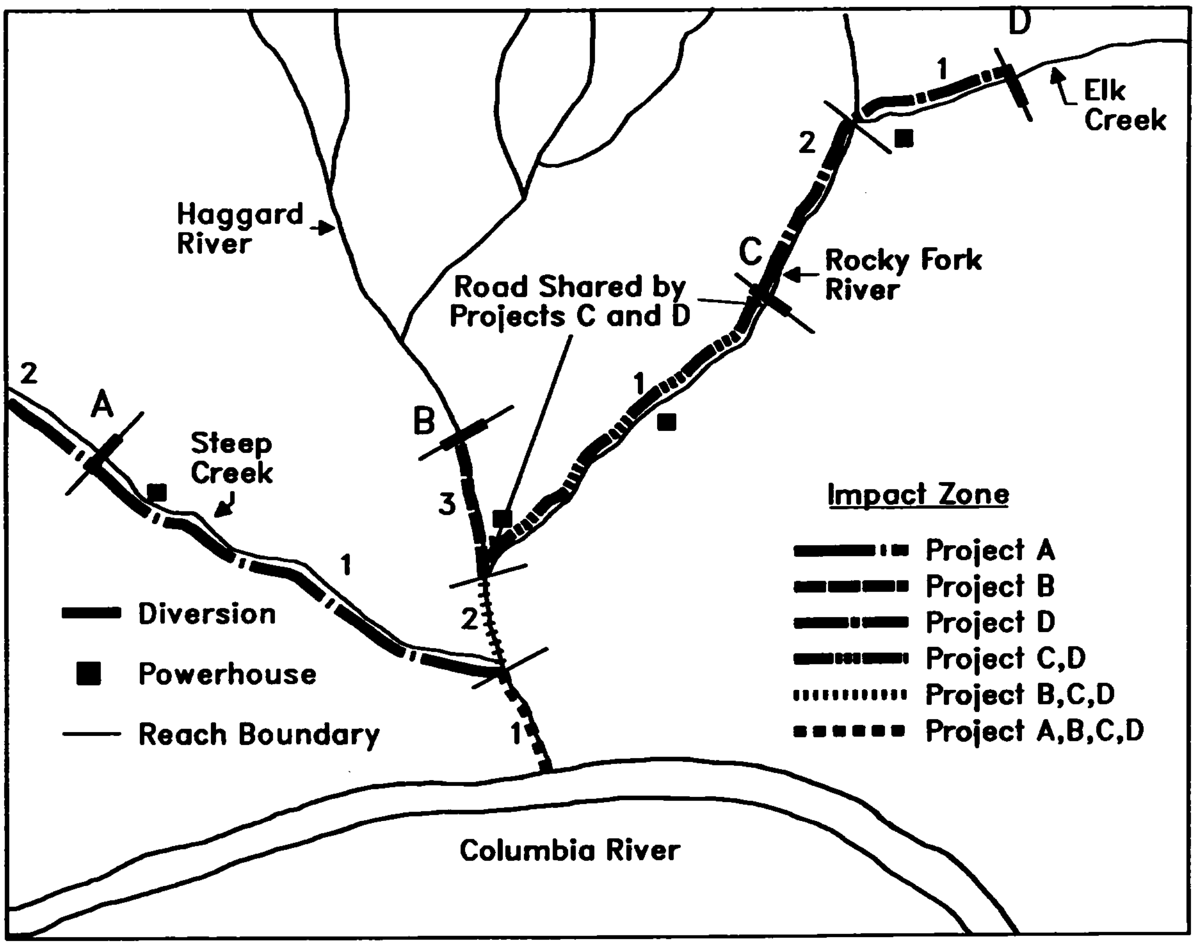

FIGURE 5.2 Project Impact Zones for Sedimentation and Passage Mortality Impacts on Chinook Salmon (road segment t is shared by projects C and D)

As shown in Fig. 5.2, the areas of project impact zone overlap include:

- Reach 1 of the Haggard River, where the impact zones of all four projects overlap,

- Reach 2 of the Haggard River, where the impact zones of three projects (Rainbow Falls, Rocky Fork, and Elk Creek) overlap, and

- Reach 1 of the Rocky Fork River, where the impact zones of two projects (Rocky Fork and Elk Creek) overlap.

The combined sediment load in the reaches of overlap was used to estimate the postconstruction emergence rates and losses of recruits for each project pair. The cumulative effects of sedimentation on salmon was expected to be infra- or supra-additive because increases in the percentage of fines in the substrate of spawning areas cause a curvilinear reduction in the percentage emergence of salmon fry (Fig. 4.6). The results of this assessment are presented in Table 5.4. One segment of new road (segment t in Fig. 5.2) would be shared by the Rocky Fork and Elk Creek Projects and would have to be considered in the calculation of cumulative effect.

5.2.3 Interaction Coefficients

Interaction coefficients for project pairs with unsegmented impact overlap zones were calculated by substituting the values presented in Table 5.5 into Eq. 3.2. Interaction coefficients for project pairs with segmented impact overlap zones were calculated by substituting the values presented in Table 5.6 into Eq. 3.3. (In both cases, these values were taken from Tables 5.3 and 5.4.) The resulting interaction coefficients for all project pairs are presented in Table 5.7.

5.2.4 Impact and Interaction Matrices and Matrix Multiplication

The elements of the impact matrix are simply the numbers of recruits lost as a consequence of each project alone (i.e., the single-project effects). The interaction matrix contains the interaction coefficients derived in Sec. 5.2.3.

Impact Matrix / Interaction Matrix

$$[160.8 \quad 7.6 \quad 146.8 \quad 166.3] \times \begin{bmatrix} 1 & 0 & 0.0006 & 0.0009 \\ 0 & 1 & 0.0395 & 0.0526 \\ 0.0007 & 0.0020 & 1 & -0.0048 \\ 0.0009 & 0.0006 & -0.0042 & 1 \end{bmatrix}$$

Product Matrix

$$= [161.1 \quad 8.0 \quad 146.5 \quad 166.2]$$

The sum of the elements in the product matrix equals 481.8.

TABLE 5.4 Cumulative Loss of Salmon Recruits Due to the Effects of Project Pairs[a]

Stream	Reach	Project Pairs[b]					
		AB	AC	AD	BC	BD	CD
Steep Creek	2[c]	5.2	5.2	5.2	0	0	0
	1	150.1	150.1	150.1	0	0	0
Haggard River	3	2.3	0	0	2.3	2.3	0
	2	4.8	21.9	26.7	27.3	32.2	27.9
	1	6.1	8.1	8.6	2.8	3.3	2.9
Rocky Fork River	2	0	0	0	0	0	0
	1	0	122.6	136.9	122.6	136.9	139.7
Elk Creek	1	0	0	0	0	0	0
Total		168.4	307.8	327.4	155.0	174.7	170.4

[a]Losses due to sedimentation effects on emergence rates in all stream reaches.

[b]A = Steep Creek, B = Rainbow Falls, C = Rocky Fork, and D = Elk Creek.

'Losses due to juvenile mortality at the diversion.

TABLE 5.5 Values Used in the Salmon Example to Calculate Interaction Coefficients for Project Pairs with Unsegmented Impact Overlap Areas[a]

Project		Zone		Population Response			
1	2	$O_{1,2}$	Z_1	$R_{1,2_o}$	R_{1_o}	R_{2_o}	R_{s_o}
A	B	5.6	160.8	6.1	5.6	0.5	0
A	C	5.6	160.8	8.1	5.6	2.3	0
A	D	5.6	160.8	8.6	5.6	2.7	0
B	A	0.5	7.6	6.1	0.5	5.6	0
C	A	2.3	146.8	8.1	2.3	5.6	0
D	A	2.7	166.3	8.6	2.7	5.6	0

[a]Values obtained from Tables 5.3 and 5.4.

TABLE 5.6 Values Used in the Salmon Example to Calculate Interaction Coefficients for Project Pairs with Segmented Impact Overlap Areas[a]

Segment	Project 1	Project 2	Zone $O_{1,2_p}$	Zone Z_1	Population Response $R_{1,2_{op}}$	$R_{1_{op}}$	$R_{2_{op}}$	$R_{s_{op}}$
Reach 1,	B	C	0.5	7.6	2.8	0.5	2.3	0
Haggard	B	D	0.5	7.6	3.3	0.5	2.7	0
River	C	B	2.3	146.8	2.8	2.3	0.5	0
	C	D	2.3	146.6	2.9	2.3	2.7	2.2
	D	B	2.7	166.3	3.3	2.7	0.5	0
	D	C	2.7	166.3	2.9	2.7	2.3	2.2
Reach 2,	B	C	4.8	7.6	27.3	4.8	21.9	0
Haggard	B	D	4.8	7.6	32.2	4.8	26.7	0
River	C	B	21.9	146.8	27.3	21.9	4.8	0
	C	D	21.9	146.8	27.9	21.9	26.7	20.8
	D	B	26.7	166.3	32.2	26.7	4.8	0
	D	C	26.7	166.3	27.9	26.7	21.9	20.6
Reach 1,	C	D	122.6	146.8	139.7	122.6	136.9	118.2
Rocky Fork	D	C	136.9	166.3	139.7	136.9	122.6	118.2
River								

[a]Values obtained from Tables 5.3 and 5.4.

5.2.5 Shared Project Features

The impacts of projects C and D both contain the impact of road segment t (Pig. 5.2) and, therefore, the sum of 481.8 derived in Sec. 5.2.4 includes the impact of this road segment twice. The sum can be adjusted for overrepresentation of the impact of this shared feature by using Eq. 3.4. The impact of this road segment was estimated as a loss of 141.2 recruits. Thus,

$$\text{Cumulative effect} = 481.8 - 141.2$$
$$= 340.6.$$

TABLE 5.7 Interaction Coefficients for the Salmon Example

Project 1	Project 2	Cl,2	Project 1	Project 2	Cl,2
A	B	0	C	A	0.0007
A	C	0.0006	C	B	0.0020
A	D	0.0009	C	D	-0.0048
B	A	0	D	A	0.0009
B	C	0.0395	D	B	0.0006
B	D	0.0526	D	C	-0.0042

Approximately 341 chinook salmon recruits are expected to be lost due to the cumulative effect of project development on fry emergence and passage mortality.

53.6 **Incorporating** the Effects of **Existing** Projects

The Columbia River Project affects the survivorship of the chinook salmon of the Haggard River Basin. The estimated increase in mortality as juveniles and adults pass the dam was incorporated into the survivorship model used to estimate the number of recruits returning to the Haggard River Basin after completion of the proposed projects. As suggested in Sec. 3.6, the number of fish lost as a consequence of proposed development would be less than if the Columbia River Project had not been built. To determine the cumulative effect of the proposed projects and the existing project, the losses attributed to the Columbia River Project (596 recruits) must be added to the value derived in Sec. 5.2.5, as per Eq. 3.5:

$$\text{Cumulative effect} = 340.6 + 596.0$$

$$= 936.6.$$

Approximately 937 chinook salmon recruits are expected to be lost from the Haggard River Basin due to the cumulative effects of the proposed projects and the existing Columbia River Project.

6 ISSUES AND CONCLUSIONS

6.1 USE OF RESPONSE CURVES

The methodology recommended in this report for calculating cumulative effects, the ITM, is based on the assumption that the impacts *of* hydroelectric development on fiih and wildlife can be assessed using models for single-project assessment that incorporate a response curve or response model. For some impacts, such as the effects of sedimentation on salmonid egg incubation or the effects of instream flow alterations on fish habitats, this assumption is correct. The Habitat Evaluation Procedures that were reviewed in Volume 1 of this report also frequently include response curves, or information that can be interpreted as such. However, for many of the hydroelectric effects listed in Volume 1, no response curves may be available, or the single-project assessment may be completed using methods that do not involve response curves. In these cases, cumulative effects can still be calculated by assuming that the effects of multiple projects are additive. Confidence in the resulting estimate will be proportional to one's professional expectation regarding the probability of nonlinear or threshold responses of the species under study.

The term "response curve" used in this report includes response models. These models may include multivariate or time-dependent relationships that simulate the complex behavior of natural systems. It is important to consider the availability of such models for cumulative effects assessment when planning a **large,** whole-basin study that is more complex than the example presented in this report.

Response curves are often constructed by regression analysis of data that exhibit a great deal of unexplained variation. Such variation reduces confidence that the interaction coefficients can adequately represent the way in which two projects will affect one another's impact. In this case, cumulative assessment can proceed with the use of a range of interaction coefficients that place upper and lower limits on the prediction of cumulative effect. The lowest reasonable values for single-project effects would be determined and used to calculate one set of response coefficients. Then, the highest reasonable values for single-project effects would be determined and used to calculate another set of response coefficients. Each set of response coefficients would be used to calculate an estimate of cumulative effect, and the two resulting estimates would be the bounds within which the actual cumulative effects would be expected to fall.

The use of response curves to calculate the effect of environmental change on populations is subject to criticism because the generality of the curves can be questioned. These curves are often constructed from data gathered over a short period of time for a specific subpopulation found in a limited area. Applying these curves to different subpopulations, geographic areas, and time periods reduces the level of confidence one has that the curves are appropriate to the situation at hand. While it would be desirable to construct specific response curves for all of the project areas under consideration, this is generally not possible, and one must decide to assume either (1) that an additive cumulative effects calculation would be more accurate than using the available response curves to estimate nonadditive effects or (2) that infra-additive and supra-additive effects are so important that the use of existing response curves would produce a more accurate calculation of cumulative effects than a strictly additive calculation.

6.2 WORST-CASE ANALYSIS

One of the advantages of the recommended methodology is that it emphasizes detailed single-project assessments, development of basic models of the relationship between environmental change and population response, and consistency in the methods of single-project assessment within groups *of* projects. All of these conditions are important for the development and regulation of hydropower projects, even if cumulative effects assessment is never routinely accomplished. Inadequate single-project assessment can lead to poor decision making, because the magnitude of the impacts cannot be stated and the risks of project development are unknown. A cumulative effects assessment cannot overcome that condition if the single-project assessments on which it is based are poor.

In the preparation of regulatory documents, such as environmental impact statements, uncertainty about the results of single-project assessments is usually overcome by assuming that project impacts will be equal to the most adverse impacts that could reasonably happen. In this "worst-case" approach, the estimated cumulative effects of projects may be greatly overstated because none of thii overstatement is lost when impacts are accumulated. The impacts may even be further overstated by the formula used to calculate interaction coefficients. For example, a worst-case assessment might lead to overstatement of the area of impact overlap (in the absence of data, the maximum overlap is assumed), which would cause the interaction coefficient to be overestimated. Since the single-project impacts are also overestimated, multiplication of the impact matrix by the interaction matrix results in a further multiplication of errors.

The usefulness of interaction coefficients is also decreased by a worst-case approach to single-project assessment. The numerator of the equation for an interaction coefficient is as follows:

$$R_{1,2_o} - (R_{1_o} + R_{2_o})$$

where:

$R_{1,2_o}$ = response of the species to the effects of both projects together in the zone of impact overlap

$R_{1_o} + R_{2_o}$ = sum of the species' responses to the effects of each project alone in the same overlap area.

If these terms are overestimated, they may fall into different regions of the response curve than would actually be the case. For ezample, for a sigmoid response curve, which has infra-additive, additive, and supra-additive regions, the response terms may be moved from one portion of the curve to another by worst-case assumptions. This not only would change the magnitude of the interaction coefficient, but also might change its **sign.** If the most likely single-project impacts would result in a supra-additive cumulative effect, the worst-case single-project impacts might result in additive or infra-additive cumulative ***effects.*** This suggests that, as confidence in the accuracy of single-project assessment decreases, the value of incorporating nonlinear responses into cumulative assessment also decreases. For worst-case analysis, an additive calculation of cumulative effects may be justified

The decision of whether to calculate interaction coefficients involves a balancing of the risks of error associated with a strictly additive cumulative effects calculation versus the risks of error associated with a cumulative effects calculation that incorporates interaction coefficients. If nonlinear biological responses are thought to be very important in controlling the degree of cumulative effect, then one may want to include interaction coefficients despite the uncertainty.

6.3 LEVEL OF DETAIL IN SINGLE-PROJECT ASSESSMENTS

In the example presented in this volume, the descriptions of habitats and population estimates for the affected resources were detailed enough to allow the use of existing models for single-project impact assessment. Since these models contain equations that define the response of the resources to environmental change, interaction coefficients could be calculated. In addition, reach-by-reach surveys ***of*** salmon redds allowed segmentation of the project impact zones for an even more accurate estimation of cumulative effects, Furthermore, single-project effects for all projects were assessed at the same time, using the same methods at the same level of detail and accuracy. All of these conditions facilitated the process of cumulative effects assessment, but they may be difficult to meet in the real world. Real river basins contain clusters of proposed and existing hydropower projects for which descriptions of habitats, estimates of population numbers, and assessment ***of*** project impacts are accomplished at different levels of detail, with different methods, and at different times. Comparable information is probably not available for all projects. The techniques used for each project may have different degrees of accuracy, yield different types of results, or be based on different assumptions or models about the response of species to environmental changes. Part of the process of cumulative assessment for a real river basin would be to find commonalities in the descriptions and assessments that can be used for cumulative assessment.

Interaction coefficients can be calculated without detailed single-project assessment, as long as some model of response is postulated. Segmentation of the impact overlap zone is not necessary and, as discussed in Sec. 4.3.1, area-based calculations of project overlap may be used. The minimum that is required for an impact zone overlap calculation is some notion of the extent of project impacts. In most cases, a single-project assessment will provide estimates of the impact's magnitude and location. Single-project impact assessments should also provide an estimate of the extent or area of the impact. If not, experienced professionals may be able to estimate the area over which the impact occurs. In the absence of any other information, it may be necessary to assume that the impact is evenly distributed throughout the impact area, so that the interaction coefficient can be estimated by assuming that the percentage of impact occurring in the area of impact overlap is determined by the percentage of the project impact zone that is in the area of overlap.

Interaction coefficients do not necessarily have to be based on real data, Single-project assessments may not be able to quantify the expected impact of the proposed projects for several possible reasons: information about the projects is insufficient for a quantitative assessment, the occurrence of a species is suspected but not known, or no quantitative assessment procedure exists for the impact under investigation. In these cases, interaction coefficients may be derived from experience and professional judgment. The team members performing the assessment can develop a scenario of possible impacts and use their knowledge of the biology of a species to infer either infra-additive or supra-additive effects. Such a procedure would be best applied when several scenarios are being assessed to develop a range of possible impacts. Thus, the sensitivity of the assessment to the missing data could be determined, and the range of values produced could be used to evaluate the risks associated with development of the projects.

6.4 SYNERGISMS AMONG DIFFERENT TYPES OF IMPACTS AND TEMPORAL EFFECTS

The recommended methodology is a way of estimating the effects *of* multiple project development on species or resources. It can be used when the incremental occurrences of an impact are thought to be greater or less than would be estimated by addition. In the ITM, any synergistic relationships among different types of impacts must be incorporated into multivariate response curves used to estimate $R_{1,2_o}$, R_{1_o}, and R_{2_o}.

For instance, temperature and sedimentation have a complex relationship in terms of their effect on the survival *of* eggs and alevins in redds. If several hydropower developments were to significantly affect both sediments and temperature, there would probably be a synergistic relationship between these two factors in their effects on fry emergence. If, however, in the assessment of cumulative effects, two univariate response curves were used, showing percentage emergence in one curve as a function of temperature and in the other as a function of the percentage of fines in the sediment, each effect would be accumulated separately, and the synergistic relationship between temperature and sedimentation would be ignored. The use of multivariate response curves that include temperature and sedimentation effects would be necessary to account for this synergistic relationship.

Temporal changes in the severity and type of impacts also add considerable complexity to cumulative assessments because the interactions among projects cannot be estimated unless important temporal effects are identified and incorporated. In some instances, impacts will be most severe during the first several years or decades following project construction and then will level off to some stable value. In other cases, impacts may be temporary and have initial effects only or have a complex pattern of temporal expression. Temporal changes are important for a variety of impacts, including sedimentation, water quality, and habitat disturbance.

Several different approaches can be taken when dealing with the effect of time. These approaches include but are not necessarily limited to (1) obtaining the average impact over the period of interest, (2) limiting the assessment to the period after the level of the resource has stabilized, or (3) using a model that incorporates time-dependent processes. In the example presented in Sec. 4.3.1, the average amount of sediment entering the stream during the fiit five years of construction was used to estimate the impact on emergence.

Models for incorporating synergistic and temporal effects are seldom available for species or other resources considered in assessments. If these effects are thought to be important ones for a particular assessment and suitable models are not available, new models would have to be developed.

6.5 USE OF DECISION-MAKING AND MODEL DEVELOPMENT TECHNIQUES

As the above discussion indicates, many decisions must be made in applying the ITM, and these decisions will affect the eventual outcome of the cumulative assessment. For this reason, we recommend that any interagency group performing such an assessment incorporate some mechanism for negotiation and decision making. The Adaptive Environmental Assessment and Management (AEAM) methodology, discussed in Volume 1, is ideal for providing a decision-making framework and for developing single-project assessment models that can be used to produce information for the cumulative assessment. Such a framework would be essential to the successful application ***of*** the ITM to any major river basin ***or*** subbasin.

The first applications of the ITM to hydropower assessment will likely emphasize the combined effects of several types of impacts on a species. In order to perform such an assessment, a multivariate model that describes the response of a species to multivariate impacts wilI be needed Since few of these models exist to date, it will be the responsibility of the group performing the assessment to develop such models. For this purpose, the AEAM will be an essential tool in the cumulative assessment.

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APPENDIX A:

DEFINITIONS OF SYMBOLS

$C_{2,1}$ Interaction coefficient describing the influence of project 1 on project 2.

E_1 Environmental change induced by project 1.

El,2 Environmental change induced by projects 1 and 2 acting together.

I_1 Impact of project 1.

I_{1_o} Impact of project 1 in area $O_{1,2}$.

$I_{1,2_o}$ Combined impact of projects 1 and 2 in area $O_{1,2}$

$O_{1,2}$ Amount of area, habitat, resource, ***or*** impact in the region of overlap of the impact zones of projects 1 and 2.

$O_{1,2_1}$ Amount of area, habitat, resource, or impact in segment 1 of the region of overlap of the impact zones of projects 1 and 2.

R_1 Response of a species to an environmental change, El, induced by project 1.

$R_{1,2_o}$ Response of a species to an environmental change induced by the combined effects of projects 1 and 2 in area $O_{1,2}$

$R_{1,2_{o1}}$ Response of a species to an environmental change induced by the combined effects of projects 1 and 2 in segment 1 of area $O_{1,2}$.

R_{1_o} Response of a species to an environmental change induced by project 1 acting alone in area $O_{1,2}$

$R_{1_{o1}}$ Response of a species to an environmental change induced by project 1 in segment 1 of area $O_{1,2}$.

R_{s_o} Response of a species to an environmental change induced by a shared project feature, s, acting alone in area $O_{1,2}$

U Unadjusted cumulative effect calculated as the sum of the elements in the product matrix.

Z_1 Amount of area, habitat, species, or impact in the entire impact zone of project 1.

APPENDIX B:

PROJECT DESCRIPTIONS

B.1 STEEP CREEK PROJECT

The Steep Creek project would be located on Steep Creek, a tributary *of* the Haggard River (Fig. 4.1). It would be a run-of-the-river facility, diverting Steep Creek waters from an area that has an average gradient of *over* 5% and an annual instream flow of about 60 cfs.

The diversion structure would be a l-m-high, 12-m-long, concrete-capped, rock-filled structure located at river kilometer (RR) 9.5 of Steep Creek. The diversion would impound 13 m of the stream and would create a 0.014-ha impoundment. The intake structure would be a l-m-wide by 2-m-long concrete box, with a removable fish screen and an 18-cm-diameter metal pipe to provide instream flows. A fish passage system would be constructed on the north side of the diversion to allow for movements of anadromous fish.

A l.5-km-long steel penstock, 41 cm in diameter, would be installed between the intake structure and the powerhouse. The penstock would be buried along its entire route beneath the proposed access road.

The powerhouse would be located on the northern bank of Steep Creek at RK 8. It would be an (8-m-wide by 8-m-long reinforced concrete strueture. Construction of the powerhouse would disrupt an area of 0.1 ha. The powerhouse would contain one vertical-impulse turbine and generator set with an installed capacity of 352 kW. Flows **from** the powerhouse would be returned to Steep Creek by a tailrace with a stilling basin at the end.

A 34.5-kV transmission line from the Steep Creek Project would be installed along and parallel to the lower 9.5 km of Steep Creek and would connect with the transmission line along the Haggard River. The 'transmission line would be installed underground beneath the proposed access road.

A 9.5-km-long access road within a l5.2-m-wide right-of-way would be constructed from the confluence of Steep Creek with the Haggard River to the diversion area on Steep Creek. The access road and its right-of-way would disturb 14.48 ha of land

B.2 RAINBOW FALLS PROJECT

The Rainbow Falls Project would be located on the Haggard River, a main tributary of the Columbia River **(Fig.** 4.1). It would be a run-of-the-river facility, diverting Haggard River waters around a 21.3-m natural falls. The average stream gradient within the reach containing the falls is 5.1%, with an annual instream flow of over 560 cfs.

The diversion structure would be an **11-m-high,** 85-m-long reinforced concrete structure located at RK 10.4 of the Haggard River. It would impound 1.45 km of the river and a total area of 11.34 ha. The intake structure would be 8.7 m hiih and 6.1 m long, with a 3.1-m by 3.1-m sluice gate located in the center of the diversion, and it would be supplied with a trash rack and fish screen. A 2-m by 2-m slide gate sluiceway would be constructed adjacent to the intake structure to pass bedload material and allow for the downstream passage of fiih. The penstock would be a 3.3-km-long rock tunnel, 335 cm in diameter, installed between the intake structure and the powerhouse.

The powerhouse would be located on the west bank of the Haggard River at RK 6.7. It would be a 30-m-wide by 28-m-long reinforced concrete structure. Construction of the powerhouse would disrupt 0.4 ha of land. The powerhouse would contain two vertical-impulse turbine and generator sets with a total installed capacity of 14.84 MW. Flows from the powerhouse would be returned to the Haggard River by a tailrace with a stilling basin at the end.

A 69-kV transmission line for the Rainbow Falls Project would be installed along and parallel to the lower 8.5 km of the Haggard River and would connect with an existing transmission line along the Columbia River. The transmission line would be installed underground beneath the existing access road.

An existing access road along the Haggard River would be utilized and no further disturbance of land would be necessary for access.

B.3 ROCKY FORK PROJECT

The Rocky Fork Project would be located on the Rocky Fork River, a tributary ***of*** the Haggard River (Fig. 4.1). It would be a run-of-the-river facility, diverting Rocky Fork River waters within an area that has an average gradient of 4.6% and an annual instream flow of about 18 cfs.

The diversion would be a l-m-high, 8-m-long reinforced concrete structure located at RK 10.4 of the Rocky Fork River. It would impound 16 m of the river for an impoundment area of 0.01 ha. A concrete apron would extend 1 m upstream and 2 m downstream of the diversion. A 1.2-m-wide by 1.7-m-high sluiceway would be constructed in the center of the diversion structure, with flows controlled by stop logs. A modified Parshall flume, with a throat width of 0.6 m, would be located on the northern side of the diversion structure to control flow to a fish ladder.

A 3.7-km-long steel penstock, 30 cm in diameter, would be installed between the intake structure and the powerhouse. The penstock would be buried along its entire route.

The powerhouse would be located on the south bank of the Rocky Fork River at RK 7.1. It would be a 15-m-wide by 14-m-long log structure with a concrete foundation. Construction ***of*** the powerhouse would disrupt 0.1 ha of land. The powerhouse would house two vertical-impulse turbine and generator sets with a total installed capacity of 430 kW. Flows from the powerhouse would be returned to the

Rocky Fork River by a taiImce channel 1 m wide and 0.6 m high. The channel would be protected by a fish screen.

A 34.5-kV transmission line for the Rocky Fork Project would be installed along and parallel to the lower 10.4 km of the Rocky Fork River and would connect with the transmission line along the Haggard River. The transmission line would be buried along its entire route beneath the proposed access road.

A 10.4-km-long access road with a 15.2-m-wide right-of-way would be constructed from the confluence of the Rocky Fork and Haggard Rivers to the diversion area on the Rocky Fork River. The access road and its right-of-way would disturb 15.85 ha of land.

B.4 ELK CREEK PROJECT

The Elk Creek Project would be located on Elk Creek, a tributary of the Rocky Fork River (Fig. 4.1). It would be a run-of-the-river facility, diverting Elk Creek waters within a reach having an average gradient of 9.9% and an annual instream flow of about 11 cfs.

The diversion structure would be a l-m-high, 5-m-long concrete weir located at RK 3 of Elk Creek. It would impound a 12-m length of stream with an impoundment area of 0.004 ha. A modified Parshall flume, with a throat width of 0.3 m, would be located on the north side of the diversion to provide instream releases. A 3.0-m by 3.3-m intake structure would be located on the southern portion of the weir. It would have a trash rack, a 0.3-m sluice pipe, and a fish screen.

A 2.8-km-long steel penstock, 30 cm in diameter, would be installed between the intake structure and the powerhouse. The penstock would be buried along its entire route beneath the proposed access road.

The powerhouse would be located on the south bank of Elk Creek, at RK 0.2. It would be 10 m wide and 6 m long, and would be constructed of reinforced concrete. Construction of the powerhouse would disrupt 0.1 ha of land. The powerhouse would house one vertical-impulse turbine and generator set with an installed capacity of 263 kW. Flows from the powerhouse would be returned through a corrugated aluminum tailrace pipe with a stilling basin at the end.

A 34.5-kV transmission line from the Elk Creek Project would be installed along and parallel to the lower 3 km of Elk Creek to the confluence of the Rocky Fork River. The transmission line would then parallel the Rocky Fork River and tie into the transmission line installed for the project. The transmission line would be installed underground beneath the proposed access road.

A 14.6-km-long access road with a 15.2-m-wide right-of-way would be constructed from the confluence of the Haggard and Rocky Fork Rivers to the diversion area on Elk Creek. The access road and its right-of-way would disturb 22.5 ha of land. If the Rocky Fork Project and its associated access road are constructed first, then the additional access road needed for the Elk Creek Project would only be 4.2 km long and would only disturb 6.4 ha of land.

B.5 COLUMBIA RIVER PROJECT

The Columbia River Project is a run-of-the-river facility located on the Columbia River. It is located 80 km downstream of the confluence of the Columbia and Haggard rivers. Average annual river flow through the facility is 150,000 cfs.

The diversion is a 38-m-high, 950-m-long concrete structure. The diversion has resulted in the creation of a 32-km-long reservoir. An overflow, gravity-type spillway is located in the middle of the diversion with 25 control gates and a discharge capacity of 800,000 cfs. A fish passage system is located on the right, left, and center abutments of the dam. Water intakes for the powerhouses are equipped with trash bars and fish screens.

There are two powerhouses located on the right and left abutments of the dam. One powerhouse has eight units with Kaplan and Naglar turbines and a total generating capacity of 210 MW. The other powerhouse has 12 units with bulb turbines and a total generating capacity of 580 MW.