ORNL/TM-11673

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Environmental Impacts of Increased Hydroelectric Development at Existing Dams

S. F. Railsback
G. F. Cada
C. H. Petrich
M. J. Sale
J. A. Shaakir-Ali
J. A. Watts
J. W. Webb

Environmental Sciences Division
Publication No. 3585

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-11673

Environmental Sciences Division

ENVIRONMENTAL IMPACTS OF INCREASED HYDROELECTRIC DEVELOPMENT AT EXISTING DAMS

S. F. Railsback
G. F. Cada
C. H. Petrich[1]
M. J. Sale
J. A. Shaakir-Ali[2]
J. A. Watts
J. W. Webb

1. Energy Division
2. Computing and Telecommunications Division

Environmental Sciences Division
Publication No. 3585

Date Published - April 1991

Prepared for the
U.S. Department of Energy
Office of Policy, Planning, and Analysis
Office of Environmental Analysis
(Budget Activity CE 10 00 00 0)

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

This report describes the environmental impacts of a proposed U.S. Department of Energy (DOE) initiative to promote the development of hydropower resources at existing dams. This development would include upgrading existing hydropower plants and retrofitting new projects at dams where no hydropower currently exists. It is estimated that by the year 2020 the following increases in the nation's hydropower capacity would result from the proposed initiative:

	Capacity increase (GW)	
	Upgrades	Retrofits
At nonfederal dams	2.2	5.8
At federal dams	2.9	4.8
Total	5.1	10.6

The plant factors (the percentage of the capacity that would actually be generated, averaged over time) for hydropower upgrades and retrofits are assumed to be 14% and 50%, respectively. Assuming that fossil-fueled plants have a plant factor of 65%, the power provided under the proposed hydropower initiative could replace approximately 9 GW of fossil-fueled capacity, or approximately 18 large (500-MW) coal-fired power plants.

Existing hydropower plants can be upgraded by (1) increasing the efficiency of the turbines and generators and (2) increasing the flow or head used by the plant. These two methods of upgrading plants cause different environmental impacts.

The efficiency of a plant can be improved by replacing obsolete or worn turbine or generator parts with new equipment, fine-tuning performance, reducing friction losses of energy, and automating operations. These efficiency improvements are expected to have only very minor and short-term environmental impacts. Replacement of turbine gates and runners (the surfaces against which water is impinged) can be environmentally beneficial because more efficient turbines generally kill fewer fish, and because new turbine parts can be designed to facilitate aeration at dams that release water with low dissolved oxygen (DO) concentrations.

Upgrading an existing plant to increase its flow or head can be accomplished by adding more turbines or replacing turbines with larger units, raising the reservoir level to increase head and storage capacity, or by reallocating the storage in a reservoir to increase the flow available for hydropower. The potential adverse effects of flow and head increases include (1) changes in downstream water quality (especially DO concentrations and temperatures) resulting from altered reservoir release patterns or from decreases in the amount of flow that is aerated when spilled from the dam, (2) changes in reservoir water quality from changes in the volume and the quality of water released, (3) reduced fish populations or growth because of water

quality changes, (4) increased entrainment and mortality of fish in turbines, (5) effects of altered reservoir levels on the terrestrial environment, and (6) altered availability of recreation. These impacts are expected to be minor in most cases, but the extent of impacts will depend on the kind of upgrade and the local environment. Most impacts would be local and could be adequately mitigated with available technology.

Retrofitting existing dams with new hydropower plants provides the benefits of new hydroelectric capacity without many of the environmental impacts of constructing new dams. New hydropower can be installed at existing storage and flood control dams, navigation dams, other kinds of impoundments, and water works such as canals and pipelines. The potential adverse environmental effects of retrofits include (1) changes in water quality (both in tailwaters and in reservoirs) resulting from changes in reservoir release volumes and qualities, (2) reductions in DO resulting from decreases in aerated spill flows, (3) mortality of fish that pass through turbines, (4) minor changes in recreational uses, and, (5) in some cases, small changes in flood elevations. As with the upgrading of existing plants, most of these impacts are local and can be adequately mitigated.

Increased hydropower capacity offers many energy security benefits. This resource is domestic and renewable. The environmental impacts of most hydropower development at existing dams are minor, so environmental concerns should not prohibit the development of most sites. However, the plant factors for projects developed at existing dams under this initiative may be lower on average than for existing operations, since the most reliable hydropower resources in the United States will have already been developed. Many new hydropower projects at existing dams may not be allowed to alter daily or seasonal flow release patterns and so may not be useful in following peaks in power demands.

The environmental impacts of fossil-fueled power generation, which would be reduced by the DOE initiative, are of greater regional and global significance than those of hydropower. These impacts include the negative effects of extraction and transportation of fossil fuels, emissions of acid-producing compounds, emissions of greenhouse gases, and disposal of large volumes of solid waste. The hydropower initiative is estimated to reduce the sulfur dioxide emissions from coal-fired generation by up to 1.3% by the year 2020. However, reductions would be less than 1% for nitrous oxides and less than 0.1% for particulates and carbon dioxide. (Hydropower would replace older fossil-fueled plants that emit more sulfur than do newer plants, which is why reductions in sulfur are predicted to be greater than reductions in other emissions. Newer plants do not generally emit less nitrous oxide or carbon dioxide than do old plants. Reductions in particulate emissions are low because almost all fossil-fueled plants currently have adequate particulate emission controls.)

Development of new hydropower capacity at new dams is a renewable energy resource that could also be partially replaced by the power resulting from the DOE initiative. Development of hydropower at new dams has impacts similar to, but of greater magnitude than, development at existing dams.

Hydropower development at existing dams has, in general, fewer impacts than development of additional fossil-fueled resources or hydropower at new dams, although potential cumulative impacts of developing multiple hydropower projects have not been explicitly addressed. Environmental review of project impacts and mitigation needs can ensure that additional hydropower development at existing dams can provide a renewable, domestic energy resource with fewer impacts than alternative resources.

1. INTRODUCTION

This report has been prepared in support of the National Energy Strategy (NES) to examine the potential environmental effects of an initiative to enhance the development of hydropower at existing dams. This initiative is being considered by the U.S. Department of Energy (DOE) as a way to increase energy resources that are domestic, renewable, and environmentally acceptable. The initiative would promote both the upgrading (increasing the capacity and energy production) of existing hydropower projects and retrofitting hydropower (constructing new projects) at existing dams. The hydropower development that would result from this proposed initiative would be in addition to the growth in hydropower production that is expected to occur without it. This report compares the environmental effects of the proposed hydropower initiative with the effects of producing the same amount of power using the energy sources that the additional hydropower would likely replace.

The regions where additional development at existing dams is most likely to occur can be predicted from data on the location of suitable dams. However, the exact sites where additional development would occur with and without the initiative are unknown at this time. Therefore, this report discusses environmental effects qualitatively, noting regional differences in impacts where they occur. Site-specific impacts of projects developed under the proposed initiative would be assessed before such projects would be (1) licensed for construction by a nonfederal entity or (2) constructed by a federal agency. This report covers only the development of additional conventional hydropower resources; it does not consider pumped storage projects.

The impacts of increased power production at existing dams are compared with impacts of two likely alternative electric power sources. Because the hydropower resulting from the proposed initiative is most likely to offset use of new or existing fossil-fueled generation and hydropower at new dams, the impacts of these other energy sources are compared with the impacts of the initiative.

2. DESCRIPTION OF PROPOSED INITIATIVE AND ALTERNATIVES

The hydropower initiative being considered by DOE would promote the upgrading of existing hydropower projects by increasing efficiency and by increasing capacity and energy production to the extent possible without unacceptable environmental impacts. The initiative would also promote the development of hydropower at existing dams where no power is currently generated. This section describes the proposed initiative and the kind of development that would occur under it. This section also briefly describes the power resources that are expected to be replaced should the hydropower initiative be implemented.

2.1 UPGRADING EXISTING HYDROPOWER PLANTS

There are many ways to increase power production at existing hydropower projects. These can generally be classified as (1) methods to increase the efficiency of power generation [producing more power per unit of flow and head (elevation difference)] and (2) methods to add to the amount of water flow or head that can be used.

Methods of increasing efficiency include

1. replacing old turbine gates (the surfaces which control the flow and direction of water entering the turbine) and runners (the turbine blades) with newer, more efficient designs;
2. replacing turbine runners with new ones of the same design to eliminate cavitation or other imperfections;
3. rewinding generators to make them more efficient;
4. fine-tuning turbine performance (e.g., gate and blade angle settings) to maximize efficiency;
5. eliminating leakage of water through gates or other structures,
6. improving trash rack cleaning to reduce friction losses of energy from them;
7. using coatings to reduce friction losses of energy in flow passages; and
8. installing automated diagnostic data collection and analysis systems.

Methods being considered by DOE to increase usable flow and head include

1. adding more turbines to utilize flow that otherwise would be spilled,
2. replacing turbines and generators with new equipment that can use a wider range of flows,
3. raising the elevation of a dam to increase its storage capacity and head, and
4. making other changes in the allocation of reservoir storage and releases.

DOE predicts that, between the years 1990 and 2020, its initiative to upgrade existing projects would result in the development of approximately 2.2 GW of generating capacity at nonfederal projects (in addition to development that would occur without the proposed initiative) and approximately 2.6 GW at projects operated by federal agencies.

The Federal Energy Regulatory Commission (FERC) Hydropower Resources Assessment data base was used to determine the location of projects most likely to benefit from upgrades. Existing hydropower projects (federal and nonfederal) that were constructed prior to 1940 and those constructed between 1940 and 1970 were identified. Projects constructed prior to 1940 are considered most likely to benefit from upgrades, but projects built between 1940 and 1970 may also gain improved power generation through upgrading. The type of turbine used at a project also affects how beneficial an upgrade could be. Figure 1 shows the locations of existing hydropower projects that may be candidates for upgrade projects because they were constructed before 1940 or between 1940 and 1970. The figure also shows whether the projects use Francis or propeller turbines. (Figure 1 includes only

ORNL-DWG 90-17202

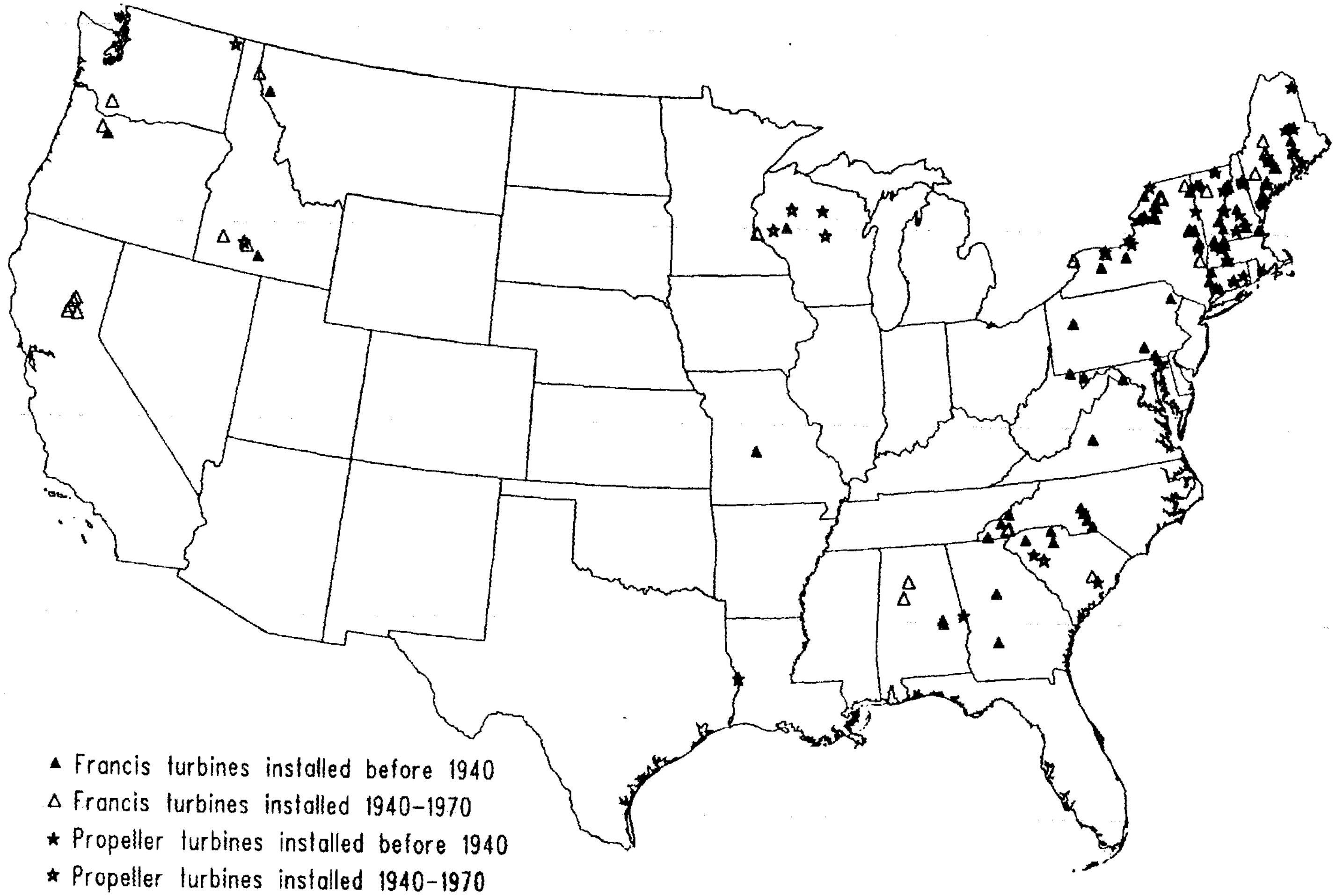

Fig. 1. Existing hydropower projects that may have upgrade potential.

the 186 projects for which adequate data were available; there are additional existing projects where either the age of the plant or the turbine type is missing in the data base. The 186 mapped projects include 95 built before 1940 with Francis turbines, 41 built between 1940 and 1970 with Francis turbines, 31 built before 1940 with propeller turbines, and 19 built between 1940 and 1970 with propeller turbines.)

2.2 RETROFITTING DAMS TO DEVELOP NEW HYDROPOWER

Testimony presented at public hearings for the NES indicated that only about 5% of 67,000 existing dams in the United States have hydropower capacity. Many of these dams are unsuitable for hydropower development because they are too small, too remote, or do not meet safety criteria. However, DOE (1990a) estimates that there are 2600 dams at which conventional hydropower could be developed. These dams include flood control and water supply reservoirs, navigation dams, abandoned or retired hydropower facilities, dams developed to provide industrial water power, and others. Some of these sites are currently being developed privately without DOE's proposed initiative, but many others are not being developed because of a combination of high development costs, relatively low energy prices, and regulatory problems (DOE 1990b).

Retrofitting a dam to generate hydropower (Fig. 2, an example at a navigation dam) usually involves (1) construction of intakes, penstocks, and a powerhouse that either replaces part of the existing structure (at low-head dams) or is located downstream (at high-head dams); (2) diversion through the turbines of water that previously was spilled through gates or over a fixed-crest or spillway; (3) construction of power lines to tie the project into the existing power grid; and (4) implementation of mitigation measures to reduce the impacts of the project. Mitigation measures may include flow release requirements, construction of fishing facilities, use of screens to keep fish out of the turbines, and water quality monitoring.

DOE predicts that its proposed initiative will result in the development, through new projects to retrofit dams between the years 1990 and 2020, of 5.8 GW of new capacity at nonfederal dams (in addition to development that would occur without the proposed initiative) and 4.8 GW of new capacity at projects operated by federal agencies.

The locations of approximately 2400 existing dams with hydro-power development potential included in the FERC Hydropower Resource Assessment data base are shown in Fig. 3. The proposed DOE initiative would result in the development of less than half of these sites (some sites are expected to remain undeveloped, and others will be developed even without the DOE initiative), but Figure 3 can be used to determine the geographic regions where dams could most likely be retrofitted to generate hydropower.

ORNL-DWG 90-17203

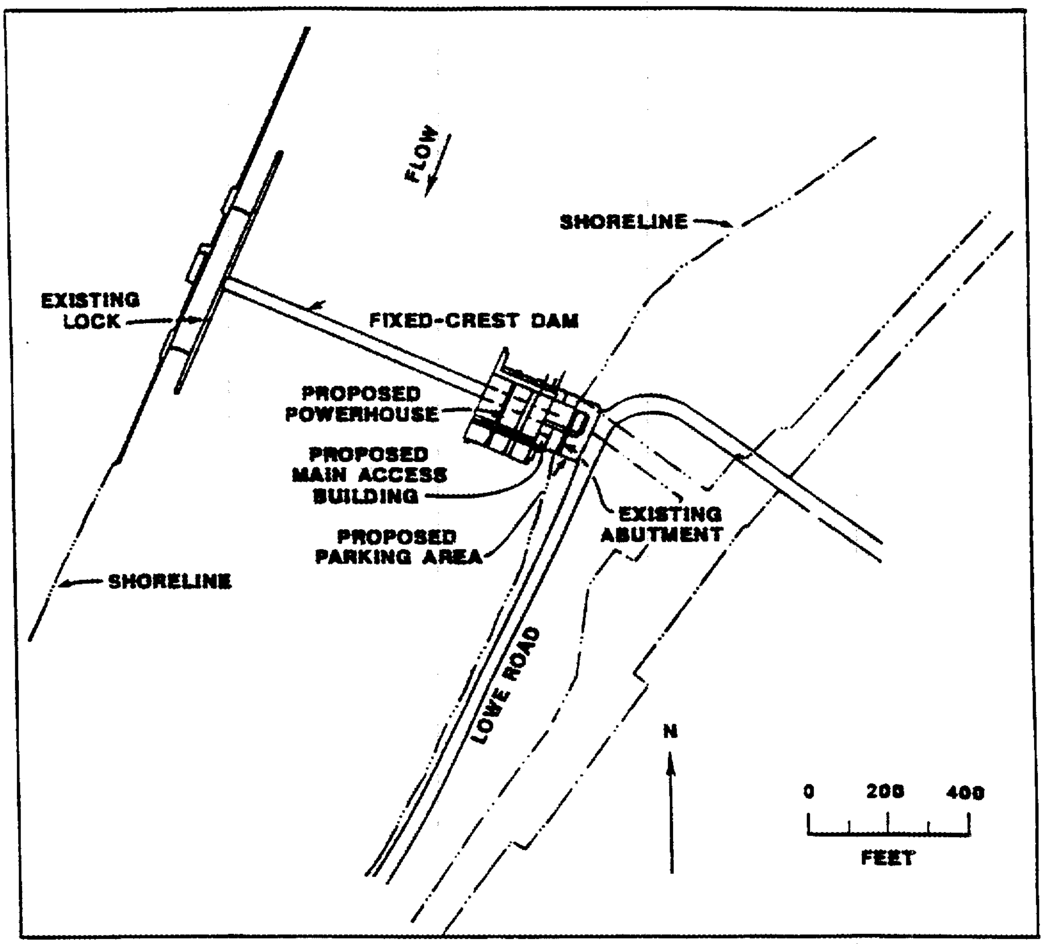

Fig. 2. Proposed retrofit of hydropower at an existing navigation dam. Source: Application for license to the Federal Energy Regulatory Commission, Allegheny River Lock and Dam No. 4 Project, FERC No. 7909, Allegheny County Hydropower Programs.

ORNL-DWG 90-17205

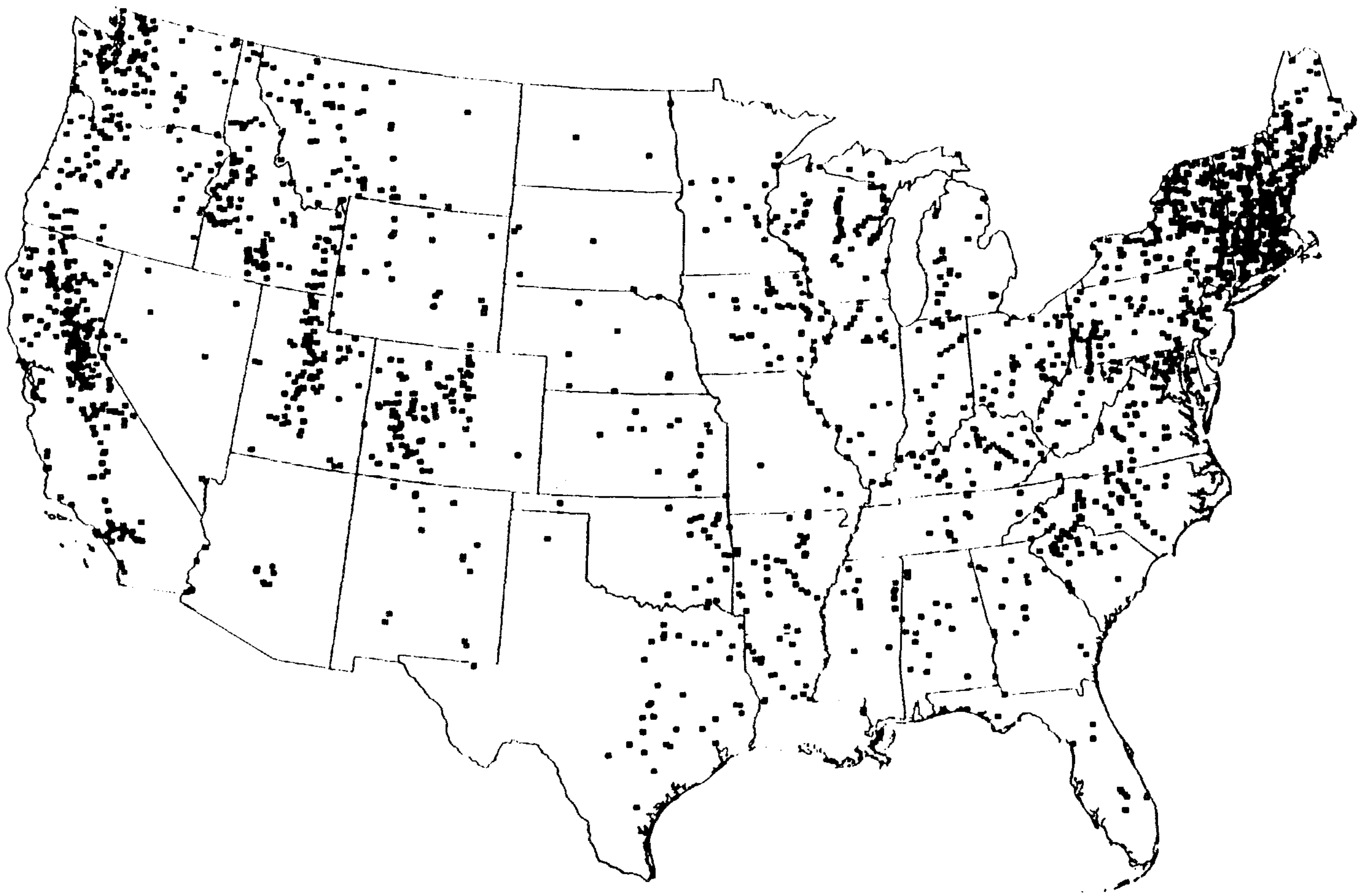

Fig. 3. Existing dams with hydropower development potential.

ORNL-DWG 90-17205

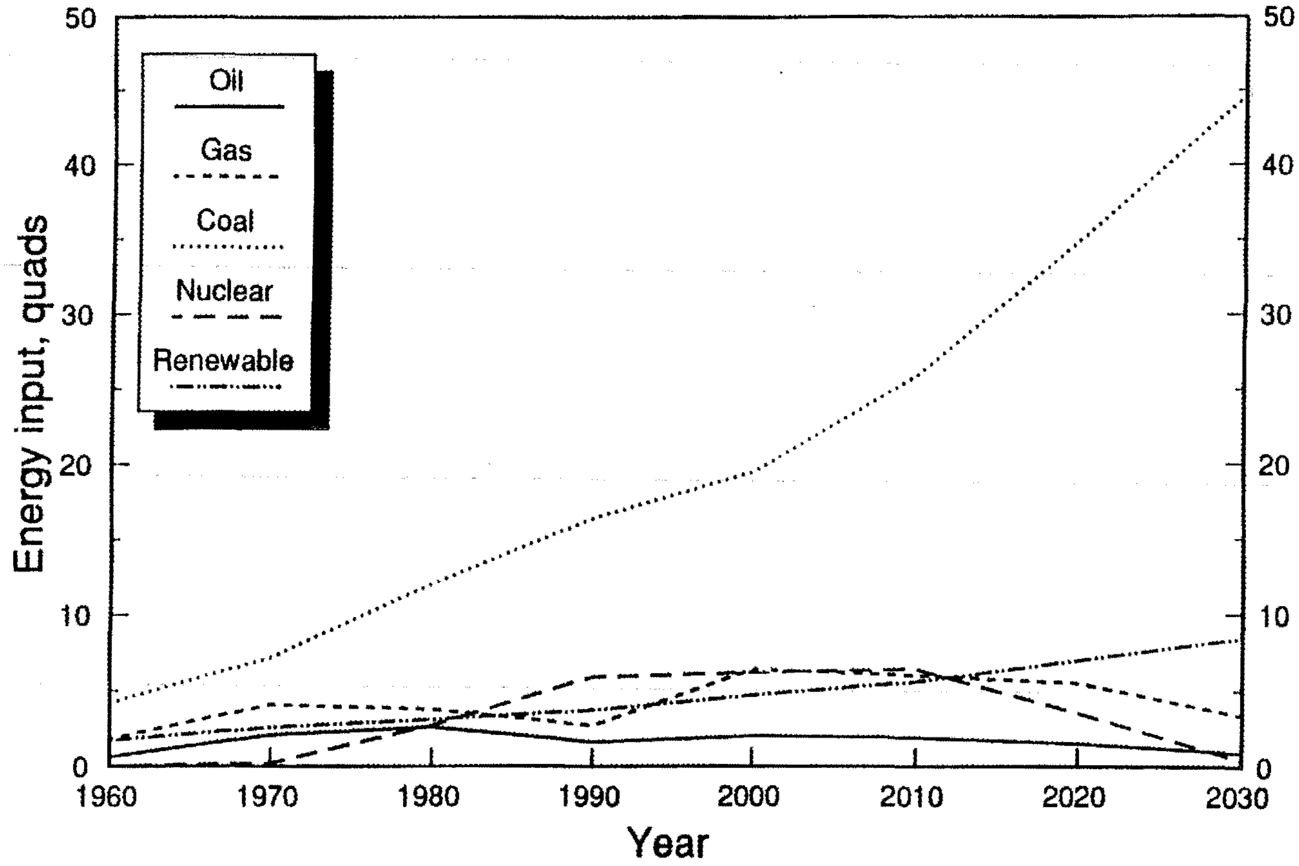

Fig. 4. Energy sources for electric power generation under the National Energy Strategy reference case.

2.3 ALTERNATIVES TO HYDROPOWER DEVELOPMENT AT EXISTING DAMS

For this report, it is assumed that energy not produced through additional hydropower development at existing dams would be provided by the mix of electric energy sources in the NES reference case. The NES reference case is DOE's prediction of the future mix of energy sources in the United States without additional policy changes. This mix is illustrated in Fig. 4, which shows U.S. energy consumption for electric power generation, from the sources oil, gas, coal, nuclear, and renewables, in units of quads (10^{15} Btu) as it is predicted to change over time.

The development of additional hydroelectric generating capacity through the DOE hydropower initiative can be assumed to replace (1) new capacity that has greater costs (including capital costs and environmental impacts) than hydropower development at existing dams or (2) existing capacity that is expensive to operate, such as obsolete plants or plants using expensive fuel. The exact mix of capacity that would be replaced by hydropower under the proposed DOE initiative can be predicted only with detailed consideration of future energy costs, the types and locations of existing and future power plants, and site-specific environmental considerations. The predicted generating capacity provided by the initiative would not have major effects on generation in any region of the United States but would probably make subtle changes in the power resources of several regions.

Figure 4 shows that most future power production under the NES reference case will be from fossil fuels, mainly coal, and that fossil fuels are also expected to provide the most growth in capacity. Therefore, it is assumed that the hydropower resulting from the DOE initiative would most likely replace additional power generation at fossil-fueled thermal electric plants. The generating capacity resulting from the DOE hydropower initiative is uncertain, but, for purposes of comparison with alternative power sources, it is assumed that the new hydroelectric capacity developed by the year 2030 under the initiative would replace 9 GW of thermal electric capacity.[1] This capacity is that of approximately 18 large coal-fired generating stations.

As discussed previously, the NES reference case includes substantial increases in hydroelectric power, including the development of new dams. Hydroelectric power is the largest component of renewable energy capacity under the NES reference case, which includes the growth in hydroelectric power generating capacity illustrated in

---

[1]This estimate is based on (1) a total of 5.1 GW of capacity, with a plant factor of 14%, for upgrades at existing hydropower projects; (2) a total of 10.6 GW of capacity, with a plant factor of 50%, for new hydropower projects at retrofitted dams; and (3) a plant factor of 65% for fossil-fueled thermal electric generation. The plant factor for upgrades is taken from DOE (1990a). The plant factors for retrofits and for fossil-fueled plants are approximate national averages.

ORNL-DWG 90-17206

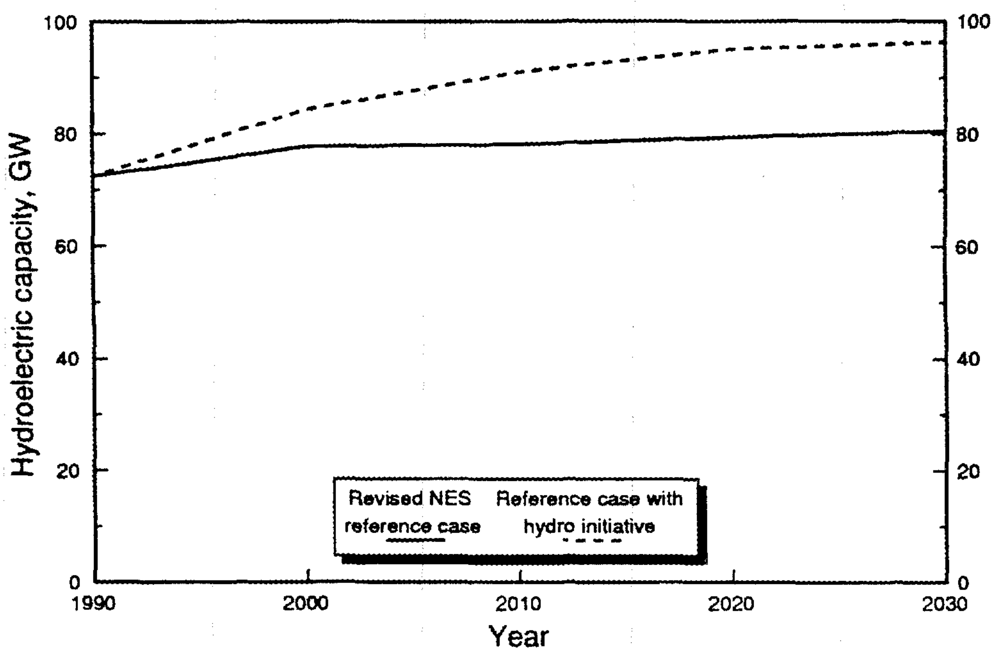

Fig. 5. Hydroelectric development predicted under the National Energy Strategy reference case, with and without the DOE initiative promoting development at existing dams.

Fig. 5 (which illustrates the growth in hydropower capacity predicted to occur with and without the proposed DOE initiative). Because additional development of hydropower at existing dams resulting from the initiative may offset some of the hydropower expected at new dams in the NES reference case, additional hydropower at new sites is discussed here as an alternative to the DOE initiative. (New hydroelectric power projects in Canada are currently an important and growing power resource, especially in the northeastern United States, where contracts for firm Canadian power supplies have recently been executed. Many Canadian hydroelectric projects are large and have had significant environmental impacts. However, the impacts of new Canadian hydropower development are not considered in this document.)

Under the NES reference case, nuclear power capacity is expected to decrease as existing plants reach their design lives and as their operating licenses expire. Therefore, additional nuclear power development is not discussed as an alternative power source.

3. ENVIRONMENTAL IMPACTS OF THE PROPOSED INITIATIVE AND ALTERNATIVES

This section discusses the environmental impacts of the hydropower development that would result from the proposed initiative and the impacts of developing the power through other means. The discussion is most detailed for hydropower development and for fossil-fueled generation, the most likely alternative. Measures to mitigate the impacts of hydropower development at existing dams are also presented. Mitigation can be costly in some cases, but the costs of mitigation and their effects on the economic viability of projects are not evaluated here.

3.1 IMPACTS OF UPGRADING EXISTING HYDROPOWER PLANTS

The environmental impacts of upgrading existing hydroelectric plants are generally minor compared with the impacts of other energy development. The impacts depend on the kind of upgrade made. Upgrades involving only replacement of turbines or generators, without changes in the volume or timing of reservoir releases, are expected to cause only minor and short-term impacts and could have some long-term environmental benefits. Upgrades that include increases in reservoir storage capacity or changes in the volume or timing of releases could have some long-term impacts.

3.1.1 Water Resources

3.1.1.1 Construction Impacts

Upgrades involving only replacement of turbines or generators, without alterations in intakes, draft tubes, or other structures, can be completed with little or no effects on water resources. Such upgrades require little outdoor work, so impacts such as erosion, disturbance of the riverbed, or fuel spill risks should be minimal. Reservoir levels and streamflows would not be changed by such upgrades.

Upgrades to install larger turbines or more turbines require more extensive construction and therefore have greater potential for impacting water resources. Such upgrades may require installation of cofferdams, dredging or excavation upstream or downstream of a dam or powerhouse, and the use of heavy machinery and outdoor storage areas. These kinds of activities can increase the local erosion of banks and streambeds during construction, resulting in increased sediment loads and potential deposition downstream. Sediments at a dam may be disturbed and redistributed by construction; if sediment contamination occurs locally then sediment redistribution may have adverse effects. The use of machinery near or in the waterway presents a risk of small fuel spills. These construction impacts are short-term, occurring only while the upgrade is being completed. It is unlikely that significant impacts on water quality (i.e., impacts that could have long-term effects on aquatic life) would occur during construction.

At upgrade projects involving extensive construction, or at simpler upgrades at projects with only one turbine, river flows in the tailwaters may be stopped for longer periods than would otherwise turbines and generators requires that there be no flow through the turbine, and at projects with storage capacity there may be no releases if the nature of the upgrade requires that all turbines be shut down. Shutting off releases to the tailwater could result in temporary dewatering and stagnation of the tailwater, contributing to high algal growth and low or highly fluctuating dissolved oxygen (DO) concentrations with consequent adverse effects on aquatic organisms.

Mitigation can be implemented to minimize or avoid most construction impacts. At multiturbine projects, normal flows in the tailwaters can be maintained by operating other turbines when one is shut down for upgrading. At some single-turbine projects, tailwater flows could be maintained, if necessary, with nongenerating releases from gates or spillways, although prolonged nongenerating releases may offset much of the benefit of upgrading. Construction impacts such as erosion and fuel spill risks are typically addressed in the licensing and permitting process for hydropower upgrades. Projects involving disturbance of the streambed or adjacent riparian zones or wetlands require permits from the U.S. Army Corps of Engineers and may also require water quality certification from the appropriate state water resources agency. These permits (which are issued under the Clean Water Act) and FERC license amendment orders for project upgrades are designed to mitigate construction impacts. Requirements of permits and FERC orders typically include development and approval of plans for (1) prevention of erosion, (2) prevention of fuel spills, and (3) deposition of dredged material. Compliance with permit and FERC licensing requirements should adequately mitigate construction impacts of major plant upgrades.

3.1.1.2 Decreased Aeration

Project upgrades can include installation of turbines capable of using higher flows at sites where some flow is otherwise spilled through gates or over spillways. Flows in excess of turbine capacity are spilled at such projects, because the existing turbines are too small to use all of the flow. The flows that are spilled may be aerated to some degree (i.e., the DO concentrations increased) during spillage. Increasing the capacity of the turbines would result in a higher percentage of the flow passing through the turbines, where little or no aeration occurs. At projects where DO concentrations are low (because of either upstream water quality impacts or impacts of the project itself), and where upgrading would result in less flow being aerated during spillage, there would be a net decrease in DO concentrations downstream. At sites where spillage occurs only during times of high flows (when DO concentrations do not tend to be low), impacts of using the spillage for power generation may not be significant. This impact tends to occur at low-head dams where the original project purpose was not hydropower and is less likely to be important at upgrades than for new hydro retrofits.

Decreases in downstream DO resulting from reduced spillage can be mitigated when necessary by requiring the project to spill flows through gates or over spillways, where aeration occurs. Such spill flows may be required during periods of low flows or high water temperatures, when DO concentrations tend to be low. Mechanical aeration processes (such as pumping air into the water as it passes through the turbine) have not yet been shown capable of economically replacing spill flows as a way of maintaining DO concentrations at low-head plants.

3.1.1.3 Improved Turbine Aeration

The replacement of turbines at projects that routinely suffer water quality problems offers the potential to reduce these problems. Many deep reservoirs stratify in summer, with a layer of cold water with low DO concentrations forming on the bottom. When this cold, deoxygenated water is released through the turbines, it provides inadequate DO in the tailwaters. Aerating the water as it passes through the turbine is one way to mitigate this problem.

Experiments with self-aerating turbines have been conducted by the Tennessee Valley Authority, the Army Corps of Engineers, and private utilities (Bohac et al. 1983, Wilhelms et al. 1987). These experiments indicate that, at some plants, turbines designed to entrain air into the flow as it passes through them could aerate the tailwaters adequately and cost-effectively (although adverse effects such as decreased efficiency and increased fish mortality can result). The upgrade of old turbines at such plants may provide an opportunity to install self-aerating turbines that could increase tailwater DO concentrations, providing a substantial environmental benefit.

3.1.1.4 Changes in Reservoir Storage and Flow Releases

Upgrade methods for existing hydropower projects include increasing or reallocating reservoir storage and increasing the flow rates used by turbines. Increasing storage is accomplished by raising the elevation of the dam. Reallocating storage generally involves changing the times at which water is released throughout the year, with resulting changes in reservoir levels. These changes can affect reservoir and downstream water quality in many of the same ways that changing the release elevation does (see Sect. 3.2.1). These impacts can include changes in water temperature and DO concentrations over time and space, which can be predicted only with site-specific modeling studies. Increased flow capacity of turbines allows the potential to increase daily flow fluctuations, the potential impacts of which are discussed in Sect. 3.2.1.2.

3.1.2 Air Quality

The air quality impacts of upgrading hydroelectric plants are expected to be local, short-term, and minor. Such impacts are likely to occur only as a result of fugitive dust emissions and emissions from machinery and vehicle use at upgrade projects requiring extensive construction. These impacts would occur only during construction and in almost all regions would be very minor compared with other emissions. There are no negative long-term air quality impacts of upgrading hydropower plants. Hydropower development can have positive effects on air quality by reducing fossil-fueled generation and its air emissions (Sect. 3.3.2).

3.1.3 Aquatic Ecosystems

The impacts to aquatic biota of upgrading existing hydropower plants result primarily from potential changes to water quality during construction and operation (see Sect. 3.1.1). Upgrades involving replacement of equipment inside buildings pose little threat for water quality degradation and subsequent biological impacts. However, substantial work outside of existing structures could lead to soil erosion and sedimentation, disturbance of contaminated sediments, and spills of construction oils and chemicals, all of which could have toxic effects on fish and other aquatic organisms (Miller et al. 1985). All sites could be affected by soil erosion and spills, but effects are readily controlled by proper construction practices. On the other hand, the possibility of encountering contaminated sediments would need to be evaluated at each site.

Changes in flow releases during construction could degrade tailwater quality (e.g., stagnation leading to increased temperatures and decreased DO concentrations). Fish and benthic invertebrates could be impacted not only by these water quality changes but also by the loss of habitat when the river below the dam is temporarily dewatered. Loss of instream habitat could range in severity from minor reduction of shallow riffle areas, which support many benthic invertebrates and some fish species, to total loss of both riffle and pool areas (Hildebrand 1980b).

Decreased aeration, as a result of passing poorly oxygenated water through a turbine instead of spilling the water over a dam, could impact tailwater biota that require high levels of DO to survive and reproduce. Effects of low DO concentrations could range from decreased growth rates to mortality among sensitive species or life stages (USEPA 1986).

Replacement of older turbines with new designs could change the turbine-passage mortality experienced by fish. Older turbines (e.g., Francis or impulse turbines) often have small passages that may cause considerable injury or mortality (Turbak et al. 1981, Ruggles and Collins 1981). Further, operation of turbines under suboptimal conditions of flow and hydraulic head may lead to high levels of cavitation, which is particularly detrimental to fish (Cada 1990). Many of the newer turbine designs have large passages and, by adjusting wicket gates and turbine blades, the capability to operate efficiently under a variety of flow conditions (Fig. 6); these improvements could lead to lower turbine-passage mortality. However, at sites where the upgrade adds capacity, passing more water through additional or larger turbines could cause greater mortality among fish that were formerly spilled over the dam.

Most of the potential impacts to aquatic biota can be controlled or mitigated by the same techniques used to protect water quality. If care is taken to minimize soil erosion, spills, and changes in flow releases, construction impacts to aquatic biota within the reservoir and in the tailwaters should be minor. Spill flows or self-aerating turbines designed to ensure adequate reaeration of water would mitigate potential low DO effects on tailwater biota. The use of multilevel intakes to remedy water quality problems may expose different reservoir fish to entrainment in the turbine intake flow. If surface waters of stratified impoundments support more fish than poorly oxygenated deep waters, increasing tailwater DO concentrations by increasing the surface withdrawal rates could exacerbate turbine-passage mortality. Considerable effort has gone into the development of fish screens for hydropower intakes (EPRI 1988); although the results have been mixed, some of these devices may be useful for reducing turbine-passage mortality at upgraded sites.

3.1.4 Riparian and Terrestrial Ecosystems

Impacts of upgrading existing power plants on terrestrial resources result mainly from construction-related disturbance to riparian habitats and wetlands. Such impacts are highly site- and project-specific but generally are likely to involve very small areas (e.g., for laydown, access, or larger facilities) and would usually be of little if any significance. In certain regions (e.g., arid landscapes of the western United States, Kondolf et al. 1988) or habitats (e.g., old-growth riparian hardwoods), the issue of construction-related disturbance could be significant for particular projects.

ORNL-DWG 90-17207

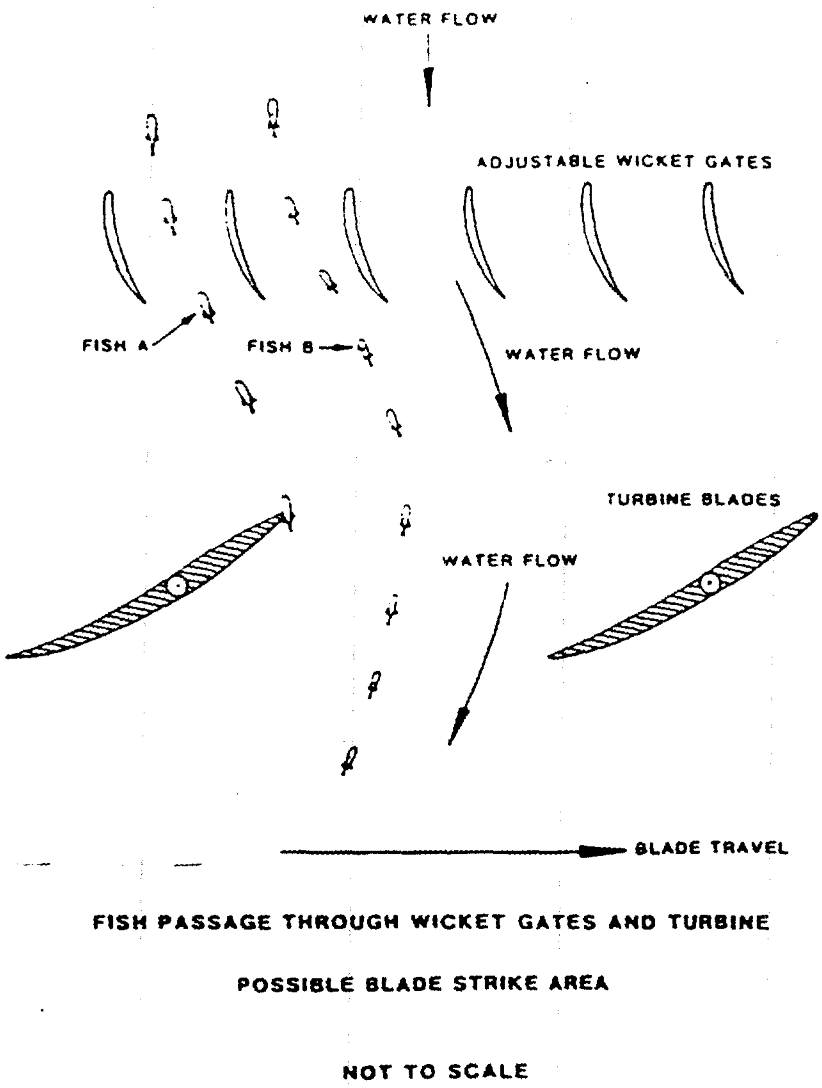

Fig. 6. Turbine passage and mortality of fish.
Source: American Electric Power, Inc.

Enhancements that involve raising dam elevations could result in significant loss of upstream terrestrial habitat through inundation (FERC 1988b). Valuable habitats that could be lost through such changes include bottomland hardwoods in the South, emergent wetlands throughout the United States, and riparian zones in semiarid or arid regions. Although such areas may be small (i.e., one to several acres) for individual projects, these habitats are increasingly valued, and the cumulative effect could be significant.

Temporary sedimentation and changes in flow regimes during construction are unlikely to have lasting effects on terrestrial resources. Similarly, replacing equipment inside buildings is unlikely to affect terrestrial resources.

Impacts to terrestrial resources can be mitigated by careful attention to siting of construction activities in relation to more important habitats and by strict adherence to erosion controls and other sound construction practices.

3.1.5 Recreation

3.1.5.1 Construction Impacts

Upgrades involving only replacement of turbines or generators without alterations in intakes or other structures would likely have few effects on recreational opportunities or resources except for limited periods during construction. More extensive alterations to dams would cause increased interruptions to normal recreational pursuits on and around hydropower reservoirs and their tailwaters. With the potential for increased sediment loads due to erosion of banks and streambeds, the water quality impacts could affect fishing, swimming, water skiing, hiking, and boating. Isolated small fuel and lubricant spills associated with the operation of heavy machinery could temporarily affect recreational activities. Such impacts would most likely be short-lived and quickly cease after construction and soil stabilization.

If reservoir waters are drawn down during construction, exposed mudflats, reduced swimming and boating areas, changed fishing habitats, etc., all affect—for the short-term and locally—the recreational opportunities available.

Fishing around tailraces is often a preferred activity for some anglers; such fishing would be affected during construction because of both water quality impacts and modifications in the normally maintained flow regimes. Temporary cessation of flows through turbines and generators during upgrades may be required, resulting in no releases through the tailraces. Potential dewatering and stagnation as a result of such constrained flows could contribute to undesirable algal growths and low DO concentrations. Other aesthetic impacts such as exposed rocks, noxious odors, loud noises, fugitive dust, gaseous hydrocarbon emissions, and eroded banks and exposed mudflats would negatively affect the expected recreational experience. Fishing may be temporarily prohibited near a project during construction.

The mitigation discussed in Sect. 3.1.1 could protect most of the recreational resources to the extent feasible.

3.1.5.2 Long-Term Impacts

Among the potential long-term effects on recreational opportunities is decreased aeration in waters released below the dams. As described in Sect. 3.1.1, new turbines could cause a decrease in available DO to fish and other aquatic species, potentially affecting the quality of the fishing experience and the aesthetics of fishing (such as through increased odors and algal growth).

At sites where turbines capable of using higher flows are installed (where some flow is otherwise spilled through gates or spillways), new flow regimes for impoundments could affect existing recreational activities such as whitewater canoeing or kayaking, swimming, and fishing. Changes in the magnitude or timing of flows downstream could affect aquatic habitats, riparian vegetation, breeding success of aquatic species, etc. All could have at least secondary effects on recreational opportunities, including safety, and the quality of the available recreational experience. Successful exploitation of available flows and head may require an increase in the height of dams and in the size of storage impoundments. Impacts would be comparable to those described in Sect. 3.2.5. The conversion of some primarily flood control dams to increase hydropower capacity could require a less tightly maintained pool, resulting in a smaller reservoir at least seasonally and possibly over the whole year. Recreation impacts would then include inappropriate dock, marina, and boat ramp elevations; exposed expanses of mudflats and/or marshy vegetation; decreased wildlife support area; and decreased fishing, swimming, and boating areas. On the positive side, less severe fluctuations in pool elevations could mean a more pleasing shoreline, less-expensive dock structures in the long term, and potentially more or improved riparian vegetation and fish habitat upstream.

Mitigation for water quality (Sect. 3.1.1) would also eliminate many recreation impacts. Projects that would alter lake elevations could make funds available to modify structures to accommodate less severe fluctuations in reservoir elevations and to relocate structures to new shoreline locations where necessary. Fishing platforms could be installed to facilitate fishing access and safety along tailwater areas, improving the fishing experience.

3.1.6 Dam Safety and Flooding

Plant upgrades that do not include increasing reservoir storage generally pose no dam safety concerns (i.e., concerns about failure of a dam and the resulting flooding). When an upgrade includes raising the reservoir levels, there are additional structural loads on the dam, and the overall factor of safety for dam failure may be reduced. The design of such a project must consider dam safety concerns. The FERC license amendment process for such upgrades includes analysis of whether the dam would continue to be safe with the raised reservoir level.

There are generally no flooding concerns at most upgrade projects. However, one way to increase generation at an existing reservoir is to reduce flood storage to provide more water for generation (Sect. 2.1). Such a reduction in flood storage would increase risks of downstream flooding; the magnitude and impacts of the additional flooding depend on site-specific factors. Any construction work that would place temporary facilities (such as cofferdams, temporary dams used to dewater construction areas) or permanent structures (such as new powerhouses) in a floodway would increase upstream water levels during floods.

3.1.7 Energy Security Benefits

The energy provided by upgrading existing hydroelectric power projects would be a relatively small portion of the additional U.S. power needs expected by 2030 (less than 1% of the increase in fossil-fueled power generation expected between 1990 and 2030 under the NES reference case), but it would be a relatively inexpensive and beneficial form of energy. Energy from such upgrades would be totally domestic and renewable, so it would not be vulnerable to foreign control or fuel shortages. Because energy from most kinds of upgrades has minimal environmental impact, environmental concerns should not prohibit its development. Energy obtained from efficiency improvements at existing projects would have the same reliability as the existing hydroelectric power. Energy obtained from increased capacity (the ability to use additional flow) at existing plants would have less reliability than the existing power, since the additional capacity would be lost first in times of low flow or if additional flow releases are needed to improve water quality or aquatic habitat. In fact, DOE (1990a) estimates that the plant factor for upgrade capacity at existing projects is 14% (i.e., energy production over time would average 14% of capacity). The ability of some projects to generate this power during peak demands greatly increases the value of the power.

3.2 IMPACTS OF NEW HYDROPOWER AT EXISTING DAMS

The installation of new hydroelectric projects at existing dams provides the benefits of additional renewable power resources without many of the adverse environmental impacts of hydropower development at new dams. The impacts that result from the impoundment of a stream have already occurred at existing dams; these impacts include alteration of aquatic habitat from flowing water to slack water in the impoundment, changes in the magnitude and timing of flows downstream of the dam, changes in water quality that occur in the impoundment and affect the tailwaters, blockage of fish migration, and submergence of terrestrial habitat by the reservoir. However, retrofitting a dam to generate hydropower can involve some additional impacts.

3.2.1 Water Resources

3.2.1.1 Construction Impacts

At low-head dams, such as navigation dams, retrofitting usually involves replacing part of the existing dam with a powerhouse or adding a powerhouse to one end of the dam. At high-head plants, such as storage reservoirs, hydropower is usually added by installing penstocks through the existing dam and constructing a powerhouse and tailrace immediately downstream of the dam. Short-term, local impacts of construction on water resources are possible. Sediment loads to the tailwaters can result from erosion at the construction site and the accidental release of excavated materials into the stream. There is a risk of small fuel spills resulting from the use of construction equipment near and in the streambed. Contaminated sediments existing at a dam may be disturbed and distributed by construction. If construction of the power plant requires temporary cessation of flow releases, the tailwater reach could be dewatered or stagnated, as discussed in Sect. 3.1.1 for hydropower upgrades. Water quality impacts of retrofit hydropower projects are unlikely to persist after construction is complete.

Mitigation to minimize or avoid construction impacts at retrofit projects would be similar to that at upgrades (Sect. 3.1.1.1). Compliance with permit and license requirements should adequately mitigate construction impacts.

3.2.1.2 Changes in Flow Release Patterns

Hydropower projects can generate more valuable power by releasing water during periods of peak daily power demands and storing it during off-peak periods. This peaking mode of operation is possible at retrofit projects built at dams with at least minimal storage capacity. The daily flow cycles that result can have adverse impacts downstream, such as stranding fish (including spawning nests and juvenile fish), posing hazards to recreational users, and increasing bank erosion. These impacts can be mitigated by (1) not allowing daily flow cycles (a common requirement) or (2) building some kind of re-regulation structure (such as another small reservoir or a low-head weir) downstream to even out daily flow cycles. Since such fluctuating flows can have adverse impacts and can conflict with the original uses of an existing dam, they are often not allowed.

Changes in seasonal release patterns would be similar to those discussed in Sect. 3.1.1.4. However, at most dams a retrofit hydropower project would not be allowed to change seasonal flow release patterns because such a change would reduce the ability of the dam to fulfill its original purposes.

3.2.1.3 Changes in Tailwater Quality Due to Changes in Release Elevation

A retrofit hydropower project can withdraw water from elevations different from the withdrawal elevations of the original impoundment.

In the case of a deep storage reservoir, water quality commonly varies with elevation, especially in summer. Thermal stratification results in an impoundment having cold water, often with low DO concentrations, in its lower elevations and warm water with relatively high DO concentrations in the higher elevations. In stratified impoundments where the existing release is from the top (over a spillway or through high-elevation gates), the installation of a hydropower plant withdrawing from low elevations would cause downstream water quality to change in summer from high to low temperatures and from high to low DO concentrations. Water released from low elevations also tends to have high concentrations of heavy metals, which can have toxic effects, and high concentrations of iron and magnesium, which are considered nuisance compounds. Even small changes in the withdrawal elevation can significantly change water quality over a summer season.

Cada et al. (1983) showed that problems with low DO concentrations in reservoir releases are much more common at large reservoirs than at small ones. Problems with low DO in releases at small hydropower projects were shown to be more common in the midwestern, southeastern, and southwestern regions of the United States. Large projects releasing low DO concentrations are most common in the midwestern, east-central, and southeastern states. Low DO problems are uncommon in winter.

In unusual circumstances even shallow impoundments, such as large rivers with low-head dams, can have stratified water quality (such as when thermal-electric power plants or upstream reservoirs contribute to temperature differences). The bulb-style turbines typically installed at low-head dams withdraw water from all levels of the upstream impoundment and eliminate stratification by mixing the water thoroughly; this mixing can actually improve water quality in situations where stratification occurs.

The release of deoxygenated water from the bottom of a reservoir can be mitigated in several ways. One way is to construct the hydropower project with a multilevel intake so that water can be withdrawn from the reservoir selectively from different elevations. Such selective withdrawal allows the project operator to release water with acceptable temperatures and DO concentrations (although water quality changes in the reservoir, discussed in Sect. 3.2.1.5, may result). Another way to mitigate the release of deoxygenated water is to aerate the water as it is released through turbines. Numerous other methods have been used to increase DO in turbine releases (Bohac et al. 1983). These methods include venting air into the turbine, with or without air pumps; pumping air or oxygen into either the tailwaters or the reservoir just upstream of the intake; forcing water from the surface layer of the reservoir down and into the turbine intakes; and, where tailwaters are adequately steep (to avoid backpressure on the turbine), installing of a weir downstream that provides aeration and evens out flow fluctuations. Such a weir is currently being designed by the Tennessee Valley Authority. The installation of a multilevel intake, aerating turbines, or other DO enhancement technologies in a retrofit hydropower project can mitigate tailwater quality problems. In cases where existing DO concentrations were high, some decrease in DO would be expected with the addition of hydropower. However, in cases where existing DO concentrations were low, better quality releases may be possible with hydropower and DO mitigation than without hydropower.

3.2.1.4 Decreases in Aeration

Installation of hydropower at some existing dams can replace well-aerated spill flows with unaerated flows through turbines. This impact is important at many low-head dams, especially navigation dams on large rivers (e.g., 19 dams considered by FERC 1988b, Sale et al. 1989, Thene et al. 1989). At low-head dams without hydropower, flows are spilled over spillways or through gates that may (or may not) provide important aeration (Railsback et al. 1990). Such spill flows may be aerated up to or above the saturation concentration of DO. This aeration can be very important for water quality since impounded rivers receive relatively little other aeration because they are deep and slow. Flows through low-head hydropower turbines receive negligible aeration. Therefore, when hydropower is installed at a dam that aerates well, the flows through the turbines do not receive the aeration they would receive without hydropower, and a net decrease in downstream DO concentrations results. The magnitude of DO reductions varies between sites and over time and may be sufficient to significantly affect fisheries. Where hydropower is installed at adjacent dams on the same river, cumulative decreases in DO could occur, resulting in DO concentrations low enough to affect fisheries (e.g., FERC 1988b).

A loss of aeration can also occur when hydropower is installed at some high-head multipurpose storage reservoirs. Some dams release cold, deoxygenated water from the bottom of a reservoir through gates and energy dissipators that greatly increase DO concentrations. This water, if released through hydropower turbines, would not be aerated, and DO concentrations downstream would be significantly reduced. Reductions in summer DO concentrations to levels harmful to fish could result without mitigation.

Loss of aeration resulting from installation of hydropower can be mitigated at both low-head and high-head plants. At low-head plants, DO concentrations can be maintained during critical periods (e.g., during summer low-flow periods) by requiring some or all of the flow to be spilled for aeration instead of being used for hydropower generation, with a resulting loss of power production. There may be ways to mechanically aerate flows cost-effectively at low-head projects, but none have been demonstrated. (Mechanical aeration is less cost-effective as a mitigation measure at low-head plants than at high-head plants because (1) much more water must be aerated per unit of power generated; (2) low-head turbines are typically designed so that water pressures are never less than atmospheric pressure, so self-aeration by venting air into the turbine at low-pressure zones is infeasible; and (3) very little research on aeration of low-head turbines has been conducted.)

Mitigation for the discharge of low-DO water from high-head plants is discussed in Sect. 3.2.1.3.

3.2.1.5 Changes in Reservoir Water Quality Due to Changes in Release Elevation

The effects on downstream water quality of installing hydropower that withdraws from different elevations of a stratified impoundment are discussed in Sect. 3.2.1.3. Changes in the elevation of withdrawal from a reservoir can also affect water quality in the impoundment upstream of the dam. For example, replacing a gate release with a turbine intake at even a small difference in elevation could reduce the amount of cold water on the bottom of a reservoir and increase the amount of warmer water in the reservoir in summer. Such changes can affect water temperatures, DO concentrations, algal production, and other water quality parameters at different times and locations in the reservoir. These effects are complex, variable, and site-specific, and reservoir simulation models are used to predict them. In some situations, the alteration of the withdrawal elevation could be beneficial for reservoir water quality (e.g., if deoxygenated water were flushed from the bottom of a reservoir), and in other situations the effects could be negative (e.g., if the reservoir volume with unsuitably high temperatures were increased).

In situations where water quality impacts on the impoundment of a proposed retrofit hydropower project were predicted to be negative, a multilevel intake for the project might be able to mitigate the impacts. However, maintaining water quality both in a reservoir and in its tailwaters may in some cases be conflicting objectives, and there may not be selective withdrawal schemes that satisfactorily prevent all water quality impacts. In some cases, water quality problems within an impoundment can be mitigated by reducing upstream sources of pollutants (e.g., wastewater discharges, non-point-source runoff) contributing to the problems.

3.2.1.6 Nitrogen Supersaturation

Nitrogen supersaturation and the gas bubble disease it causes in fish are commonly associated with hydropower projects. Gas bubble disease occurs in fish exposed to water supersaturated with dissolved nitrogen. The disease results in formation of gas bubbles within the fishes' bodies and can cause mortality at nitrogen concentrations as little as 105% of saturation (Norwegian Hydrodynamics Laboratories 1984). Nitrogen supersaturation can occur when air is entrained into poorly designed penstocks, when water saturated with nitrogen deep in a reservoir (where pressure increases the saturation concentration) is released to tailwaters, and when reservoir releases are very highly aerated (Wolke et al. 1975). Nitrogen supersaturation is not commonly found at dams suitable for addition of hydropower, and, although gas bubble disease may occasionally occur because of site-specific conditions, it is not expected to be a significant adverse impact of hydropower development at retrofitted dams.

3.2.2 Air Quality

As with upgrading hydropower projects (Sect. 3.1.2), the air quality impacts of retrofitting dams with hydroelectric plants are expected to be local, short-term, and minor. Impacts such as fugitive dust emissions and emissions from machinery and vehicle use would occur only during construction and in almost all regions would be very minor compared with other emissions.

3.2.3 Aquatic Ecosystems

Construction impacts to aquatic resources from retrofit hydropower development would be similar in nature to those associated with upgrading existing hydroelectric plants (Sect. 3.1.3). However, because construction is likely to be more extensive under this alternative, the potential for impacts to aquatic resources, especially from water quality degradation, is greater. Also, the mitigative measures needed to control these potential impacts would be similar to those described in Sect. 3.1.1.

Operation of a retrofitted dam could impact aquatic organisms through habitat and water quality degradation. Although the reservoir already exists and the biological communities have adapted to the lake environment, commencement of hydropower production may alter the magnitude and timing of releases. This in turn could result in rapid and more extreme water level fluctuations in both the reservoir and tailwaters, which degrade important shallow-water habitat for aquatic biota (Hildebrand 1980b).

The release of cool, poorly oxygenated, deep water from stratified reservoirs will degrade the water quality of the tailwaters and adversely impact tailwater communities that are adapted to releases of warmer, well-oxygenated surface waters. As with the potential decreased aeration problem described for the upgrade alternative (Sect. 3.1.3), effects can range from decreased growth rates to mortality. The mitigative measures suggested in Sect. 3.2.1 to enhance DO concentrations of new hydropower releases should also serve to protect tailwater biota. The use of multilevel intakes to correct low DO problems would need to take into account not only the DO requirements but also the temperature requirements of aquatic organisms below the reservoir. An additional complicating factor associated with the use of multilevel intakes is that withdrawal of water from different levels of the reservoir may expose different reservoir fish to entrainment in the turbine intake flow. If surface waters support more fish than deoxygenated deep waters, correcting water quality problems by increasing the surface withdrawal rates could exacerbate turbine-passage mortality.

Water quality changes within the reservoir resulting from new hydropower releases could have either beneficial or adverse effects on aquatic organisms. Releases of poorly oxygenated deep water could increase the amount of well-oxygenated habitat available to both fish and bottom-dwelling invertebrates in a stratified reservoir. On the other hand, releases of surface water, for example to correct tail-water quality problems, may reduce the amount of adequately oxygenated habitat for reservoir biota. Because different release schemes will alter impoundment temperatures as well as DO concentrations, the thermal requirements of reservoir organisms must also be considered. As with water quality considerations (Sect. 3.2.1), such effects are complex, variable, and must be evaluated on a site-specific basis.

Turbine-passage mortality would be a new impact of installing hydroelectric facilities at existing dams. The seriousness of this issue depends on a number of factors, including the species of fish affected; sport fish are generally of greater concern than rough fish. Behavior of the fish has an important influence on turbine passage mortality. Bottom-dwelling species may not encounter surface-level intakes. Anadromous fish such as salmon, American shad, and striped bass must migrate downstream and therefore must pass over the dam either in spill flows or through the turbines; on the other hand, many inland fish species in reservoirs do not move great distances and may not be exposed to turbine intake flows. Finally, the size of the fish entrained in the intake flow is important in that large fish are more likely than small fish to be injured by turbine passage (Cada 1990). Different turbine types cause different mortality rates: in general, the farther apart the blades are, the lower the mortality, although other factors are also important.

3.2.4 Riparian and Terrestrial Ecosystems

The impacts to terrestrial resources from retrofits are similar to those from upgrading existing hydroelectric plants (Sect. 3.1.4). However, because more extensive construction is likely under this alternative (e.g., several to many acres for powerhouse, penstock, access, parking, and transmission lines), the potential for disturbance to riparian habitats and wetlands is greater. The installation of new power lines, in addition to disturbing habitat, may pose collision hazards for birds and bats and electrocution hazards for large raptors. The latter can be mitigated by proper tower design. Other mitigative measures needed to control these potential impacts would be similar to those described in Sect. 3.1.4.

Hydropower production at retrofitted dams may alter flow releases, thereby affecting shallow-water habitat including emergent vegetation in wetlands near tailwaters. Altered flow regimes may also alter reservoir levels enough to affect upstream wetlands and riparian zones. The seriousness of such effects depends on the extent and value of wetlands present; effects would normally be small for individual projects but could be cumulatively significant.

Projects that produce electricity by diverting water through penstocks for significant distances may produce losses or undesirable changes to riparian zones along dewatered reaches. Such damage is particularly serious in semiarid or arid regions where streamside vegetation is particularly important ecologically (Kondolf et al. 1988).

3.2.5 Recreation

3.2.5.1 Construction Impacts

The retrofitting of dams to generate new hydropower will entail many of the same construction effects as described in Sect. 3.1.5.1. Where new penstocks and powerhouses are required downstream of the existing dams (high-head situations), significantly more riparian disturbances are likely. This could affect fishing, hiking, swimming, boating, nature observation, and access to any of these. If construction of the power plant requires temporary cessation of flow releases, the tailwater reach could be at least partially dewatered, and the remaining waters could become stagnant, as discussed in Sect. 3.1.5.1. Fishing in dam tailwaters could be prohibited during construction.

If greater impoundments are needed to accommodate the flow requirements of the new generation capability, a variety of impacts can be expected. Construction could bring erosion and sedimentation impacts to water quality, affecting fishing, swimming, and boating. Recreational activities could be directly affected by construction noises, aesthetic impacts of heavy machinery in a recreational environment, and temporary cessation of activities because of safety concerns.

The mitigation strategies outlined in Sect. 3.2.1 would be appropriate to partially protect water quality-dependent recreation resources. Normal flows should be maintained in tailwaters via use of flows from gates or spillways.

3.2.5.2 Long-Term Impacts

Retrofitted dams could create local impacts due to the presence of mechanized fish screens in place of simple spillways and gates. These could affect swimmers, scuba divers, boaters, nature watchers, and anglers who normally use the waters near the dam area for their recreational pursuits.

Sect. 3.2.1 describes the potential reservoir water quality impacts due to changes in release elevation. These possible changes could affect swimming, fishing, and wildlife observation at different times of the year and in different locations around the reservoir.

Long-term effects of expanding reservoir sizes to accommodate new hydropower generation regimes could result in both negative and positive impacts for recreational resources. Increased impoundment size could mean greater expanses of calm water for sailing, rowing, fishing, and swimming. On the negative side, access to the water could be changed due to higher water levels. For example, docks, boat ramps and marinas might have to be relocated or redesigned to accommodate the higher or more frequently changing water levels. Riparian vegetation and riparian aquatic habitat of some sports fisheries could be lost to expanded impoundments. Wildlife, possibly seasonal wildlife, could be affected by changes in the water regime in impoundments. This could affect hunting, fishing, and nature watching.

Anglers accustomed to using tailwaters might have to adjust to the changed water release regimes that would accompany conversion to hydropower development. There could be safety risks to boaters and fisherman who use the areas immediately downstream of the newly converted dams. The smaller impoundments of the New England area might experience some changes in recreational use or potential with modest augmentation of reservoir size. Similarly, the loss of free-flowing upstream waters and their associated recreational resources could mean some loss of recreational and aesthetic resources. On the larger reservoirs used for navigation and flood control in other areas, the increased surface areas would also likely be only modestly increased.

As described in Sect. 3.2.1, the installation of new hydropower facilities at existing impoundments can result in the withdrawal of water from different depths than was the case prior to conversion. The net result can be significant changes in water temperatures and in DO concentrations—potentially negative effects on fishing and swimming.

Mitigation can be provided for many impacts to recreation. Horns or warning whistles could notify recreational users just below retrofitted dams of the dangers of sudden water releases and the associated potential for rapid changes in water levels. Warning signs could also be posted on both riverbanks. Funds could be made available to compensate riparian owners who might have to lose lakeshore property, move docks or boat ramps, or otherwise change or redesign their use of the reservoir area. Fishing platforms could be installed to facilitate fishing access and safety along tailwaters areas.

3.2.6 Dam Safety and Flooding

3.2.6.1 Dam Safety

Some dam safety concerns are associated with retrofitting dams with hydropower. Removal of some parts of existing dams is usually required for installation of powerhouses and penstocks. This demolition must be conducted properly to avoid weakening the structure or foundation of the dam. The new structures and cofferdams must be properly designed and constructed to avoid failure.

When a hydropower dam operated by a federal agency (e.g., the Army Corps of Engineers or the Bureau of Reclamation) is retrofitted, the agency reviews the plans prepared by the hydropower developer and oversees all demolition and construction work. The agency retains responsibility for dam safety during construction and operation of the hydropower project. The agency review process and oversight responsibility are designed to prevent hydropower development from significantly increasing risks of dam failure.

When a hydropower project is proposed at a dam not operated by a federal agency, FERC evaluates dam safety as part of the licensing process. If the dam does not meet FERC's safety criteria, the project will not be licensed unless the hydropower proponent agrees to bring the dam into compliance with the safety criteria. If the project is licensed, the licensee assumes responsibility for the safety of the dam. The FERC requirement for a hydropower developer to assume responsibility for safety of an existing dam may discourage development at some dams but is designed to prevent hydropower development from significantly increasing the risk of dam failure. In cases where existing dams would be upgraded to meet FERC's safety criteria, an increase in dam safety would result from hydropower development.

3.2.6.2 Flooding

The construction of hydropower projects at low-head dams may, depending on design, increase the magnitude and frequency of flooding upstream (Schmitt and Varga 1988). For example, hydraulic modeling studies for powerhouses built at two existing navigation dams on the Allegheny River predicted that water levels during extreme floods would increase by up to 2 ft. as a result of the hydraulic resistance of the powerhouse. (Floodwaters would flow over the powerhouse less smoothly than over the existing dam.) During construction of projects, any obstruction (especially cofferdams) in the path of flood flows would increase the upstream flood elevations.

The potential increases in upstream flooding caused by retrofit hydropower projects can be studied with hydraulic models. Projects can be designed to minimize effects on flood elevations. At projects where some increases in flood elevation are unavoidable, hydropower developers can avoid the financial impacts of increased flood elevations by purchasing flood easements.

3.2.7 Energy Security Benefits

The energy provided by retrofit hydropower projects would be a relatively small portion of the additional U.S. power needs expected by 2030 (less than 1% of the increase in fossil-fueled power generation expected between 1990 and 2030 under the NES reference case), but it would be relatively inexpensive and beneficial energy. This hydroelectric resource would be totally domestic and renewable, so it would not be subject to foreign control or fuel shortages. Development at many existing dams could have minimal environmental impacts, so environmental concerns should not prohibit it. (However, real and perceived environmental impacts could lead to strong opposition to development at some existing dams.)

Energy obtained from many retrofitted dams, such as storage projects and navigation dams, would be as reliable as that from most existing hydroelectric projects. However, new power capacity at some kinds of dams, such as small projects, may provide less-reliable power because flows too low to generate occur frequently. Few retrofitted dams are expected to be allowed to use peaking operation or to otherwise change storage patterns, so the projects would tend not to be useful for following daily or seasonal cycles of demand.

3.3 IMPACTS OF GENERATION USING FOSSIL FUELS

Generation using fossil fuels (coal, gas, and oil) accounts for most U.S. capacity and is likely to provide most of the power that would otherwise be generated by hydropower under the proposed DOE initiative. The power provided under the initiative could replace the capacity of approximately 18 large (500-MW) fossil power plants. The environmental impacts of fossil-fueled generation have been described in other studies, including Dvorak et al. (1978) and DOE (1989).

3.3.1 Water Resources

Fossil-fueled generation causes a number of impacts to water resources. Fossil plants are generally constructed adjacent to large bodies of water, which provide cooling water and, sometimes, barge transportation of fuel. The construction of plants disturbs large land areas, which can increase erosion and, consequently, stream sediment loads.

Many water resources impacts of coal-fired generation result from coal mining and transportation. Coal mines in humid regions (such as the eastern United States) have historically caused severe degradation of water resources as a result of stream channel alteration (from direct effects of mining, hydrologic changes to watersheds, and increased sediment loads) and acid mine drainage. These impacts can be controlled to some extent but cannot be totally avoided. In arid regions, impacts of mining to water resources are generally less than in humid regions, although some impacts such as changes in groundwater can occur. Transportation of fossil fuels by barge on existing waterways generally has minor impacts on water resources, but some other modes of fuel transportation, such as coal slurry pipelines, can have major effects on local water resources. Coal is often washed at the mine or power plant to improve its burning and emissions qualities; this process consumes and degrades the quality of large amounts of water.

The production and transportation of gas and oil for electric power production also have impacts on water resources. These include impacts of offshore oil development and oil spills during transportation and refining.

The operation of fossil-fueled power plants causes a number of impacts to water resources. These plants require cooling water to condense steam prior to its reuse in the boilers. Cooling water can be used either once and discharged to surface waters or recycled using a cooling tower to release the heat to the atmosphere. Once-through cooling can cause significant temperature increases and evaporation in the receiving body of water. Cooling towers consume water by evaporating it and require the release of blowdown water, which has higher-than-natural concentrations of dissolved solids. On average, cooling is estimated to consume 1500 liters of water per megawatt-hour of power generation (DOE 1989). There are other smaller wastewater streams from fossil-fired power plants, such as boiler blowdown and scrubber effluents. Runoff from coal, fly ash, and scrubber sludge storage areas are other wastewater sources which, if not controlled, can release toxic compounds into surface water or groundwater. Water consumption for coal cleaning, scrubbers, and other uses besides cooling is estimated to average 2300 liters per megawatt-hour (DOE 1989).

Air emissions from fossil-fueled power generation have important regional impacts on water quality. Coal-fired power generation contributes large fractions of sulfur and nitrous oxide emissions, which cause acid deposition. The effects of acid deposition (both as precipitation and dry deposition) on water resources is being studied by the National Acid Precipitation Assessment Program (e.g., Malanchuk and Turner 1987, NAPAP 1990). The effects of acid deposition vary regionally with deposition rates and also depend on local geology. The regions most at risk from acid deposition from U.S. power plants appear to be the northeastern United States and some of southeastern Canada.

Global water resources could be affected increasing carbon dioxide emissions (Waggoner 1990). The effects of increased greenhouse gas concentrations in the atmosphere are poorly understood, but regional changes in the amounts and timing of precipitation, air temperatures, winds, and vegetation types, all of which could result from global warming, would have major effects on water availability and water quality in many parts of the world.

3.3.2 Air Quality

Unlike hydroelectric generation, power generation using fossil fuels is a major source of air emissions. Emissions include fugitive dust releases from coal piles and mines, emissions from vehicles used to mine and transport fossil fuels, volatile hydrocarbon emissions from the storage and handling of petroleum and gas, and combustion emissions.

The air quality impact of fossil-fueled generation that is of greatest concern is the emission of the combustion products sulfur dioxide, nitrous oxides, particulates, and carbon dioxide. Fossil-fired electric power generation produces approximately 70% of U.S. sulfur emissions and 40% of nitrous oxide emissions but only about 10% of particulate emissions (Placet et al. 1986). These emissions are mostly from coal and oil combustion; natural gas-fired plants have significantly lower air emissions.

Sulfur dioxide and nitrous oxides are of concern mainly because they contribute to acidic precipitation and dry deposition, although they may also affect human health. Particulates have adverse effects on human health, weather, and visibility.

Carbon dioxide emissions are also of concern because of their contribution to potential greenhouse warming of the earth. Carbon dioxide emissions have risen steadily since at least the 1950s. It appears that approximately half of the carbon dioxide emitted remains in the atmosphere, where it may contribute to global warming, and the rest is dissolved in the oceans, taken up by vegetation, or otherwise sequestered (DOE 1989). Coal-fired generation in the United States contributes about 8% of the current global carbon dioxide emissions from energy consumption (including transportation). Fossil-fueled power generation in the United States is one of the largest single sources of carbon dioxide emissions but is still a relatively small part of the global emissions and activities that contribute to climate change concerns.

Many technologies (referred to as clean coal technologies) are potentially capable of reducing emissions of sulfur and nitrogen compounds from fossil-fueled plants (DOE 1989). These technologies are expected to be used even more in the future, especially following passage of the 1990 revisions of the Clean Air Act. However, no technologies exist to significantly reduce carbon dioxide emissions of fossil-fueled generation.

The effects on air emissions of replacing 9 GW of coal-fired capacity with hydropower were analyzed. Hydropower would result in greater reductions in air emissions if it were developed quickly, replacing existing conventional coal-fired capacity before most coal-fired plants are converted to or replaced by clean coal technologies (DOE 1989). The scenario simulated is the replacement, over the period 1995-2010, of 2.25 GW of coal generation every 5 years. Predictions of air emissions from all electric utilities for 1990 to 2020 without the hydropower initiative are those estimated by DOE for the NES reference case; these predictions are based on actual emissions in 1987. It was assumed that coal-fired plants without clean coal technologies would be replaced by the additional hydropower. Table 1 gives the air emissions predicted under the NES reference case, and Table 2 gives the emissions predicted with the hydropower initiative.

With the hydropower initiative, emissions of particulate matter are predicted to change negligibly from the baseline case. This finding is attributed to the high removal rate of TSP at existing coal plants. The impacts of the hydropower initiative on sulfur dioxide, nitrous oxides, and carbon dioxide emissions are shown in Fig. 7. The predicted reduction in sulfur is 2.2% by the year 2010. Hydropower developed after about 2010 may replace power generated at relatively new plants (built during or after the 1980s) that use clean coal technologies and emit less sulfur. Therefore, hydropower developed after 2010 would be less beneficial in reducing emissions than would hydropower developed before 2010. The hydropower initiative would result in decreases of 2.1% in nitrous oxide emissions and 1.0% in carbon dioxide emissions from electric utilities by 2010.

3.3.3 Aquatic Ecosystems

Many of the impacts to aquatic ecological resources from construction and operation of fossil-fueled power plants are much different in kind and magnitude than impacts from the various hydropower alternatives. Most of the construction of fossil plants occurs on land, and the same mitigative measures discussed in Sects. 3.1.1 and 3.2.1 to control erosion, sedimentation, and construction spills at hydroelectric facilities can be employed to minimize aquatic impacts at fossil plants. Unless the fossil plant creates a cooling lake, losses of aquatic habitat are generally relatively small, comparable to those resulting from by upgrading or retrofitting existing reservoirs, and much less than the amount of riverine habitat lost to a new hydroelectric impoundment.

Operation of the condenser cooling system of a fossil plant can impact aquatic organisms through entrainment, impingement, and

Table 1. Predicted emissions from electric utilities under the National Energy Strategy reference case, and 1987 base values

Year C/year)	SO_2 (10^3 tons/year)	NO_x (10^3 tons/year)	CO_2 (10^6 tons
1987	14630	6651	479
1990	14911	6737	495
1995	16426	7524	562
2000	17787	8370	653
2005	18231	8885	752
2010	18730	9496	863
2015	18811	10149	994
2020	17242	10086	1117
2025	15410	9986	1241
2030	13841	9859	1364

Table 2. Predicted emissions from electric utilities with the DOE hydropower initiative, and 1987 base values

Year C/year)	SO_2 (10^3 tons/year)	NO_x (10^3 tons/year)	CO_2 (10^6 tons
1987	14630	6651	479
1990	14911	6737	495
1995	16324	7473	560
2000	17582	8268	648
2005	17924	8732	745
2010	18324	9292	854
2015	18405	9945	985
2020	16836	9882	1108
2025	15004	9782	1232
2030	13435	9655	1355

ORNL-DWG 90-17208

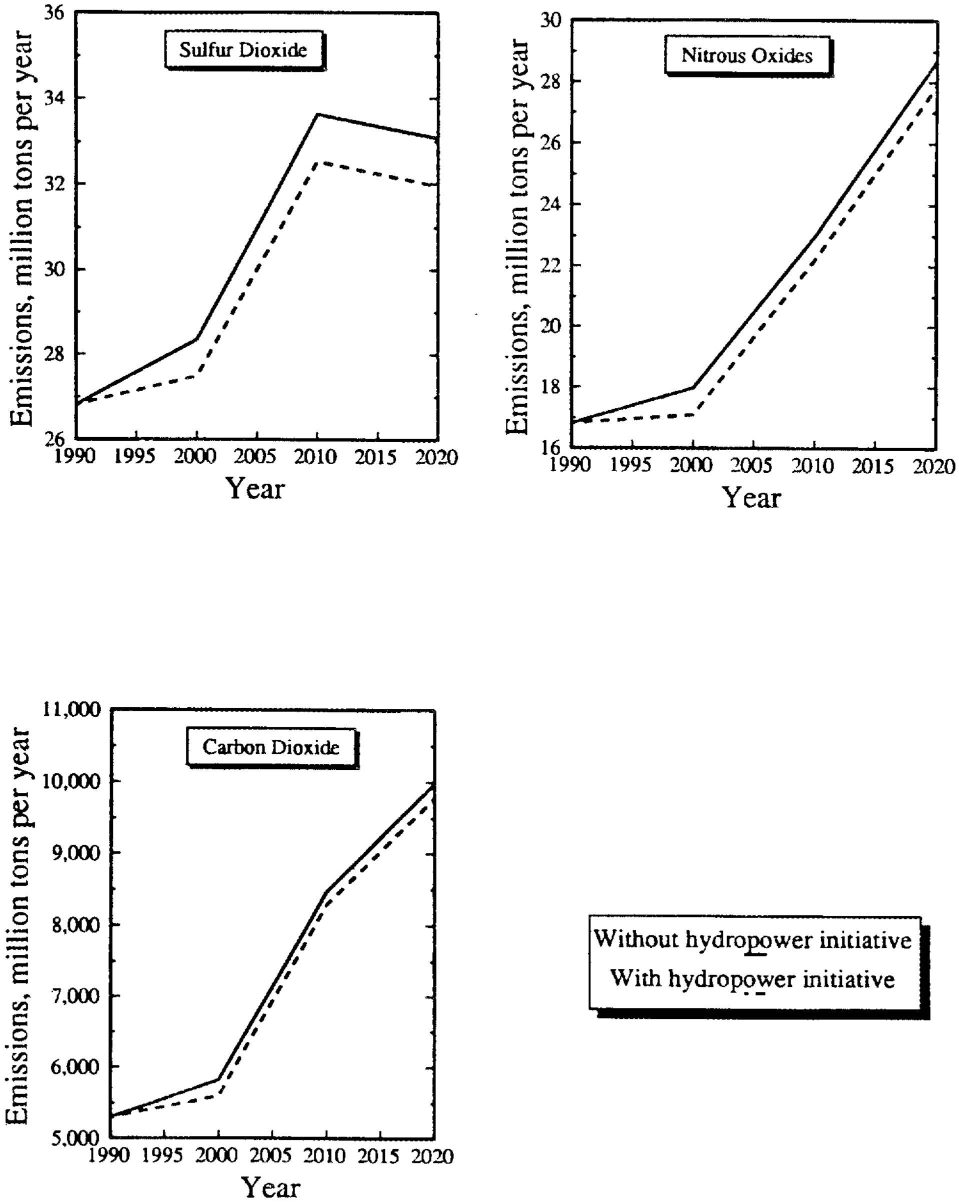

Fig. 7. Air emissions from electric utilities with and without hydropower from the DOE initiative.

chemical and thermal discharges (Langford 1983). The amounts of water used to cool the power plant condenser can be large; a 1000-MW power plant with once-through cooling discharges about 48 cubic meters of water per second (761,000 gallons per minute) at a temperature elevated 10°C (18°F) (Coutant 1981). Large numbers of aquatic organisms may suffer mortality as a result of being drawn through the cooling system (entrainment) or being trapped against the fine-mesh debris screens in the intake (impingement). Periodic discharge of chlorine or other chemicals and continuous discharge of heat can affect aquatic life in the receiving water.

Coal-fired power plants produce large amounts of solid waste (e.g., combustion ash and scrubber sludges). Leachates from both coal and ash piles can degrade water quality and have toxic effects on aquatic biota if not controlled. In addition to effects at the power generation site, water quality impacts or habitat losses associated with the entire fuel cycle (coal and oil extraction, refinement or cleaning, and ash disposal) can have significant impacts on aquatic communities over larger geographic areas (Hunsaker et al. 1990). Acid deposition from fossil plants (Sect. 3.3.1) can also affect aquatic biota in widespread areas.

3.3.4 Terrestrial Ecosystems

Impacts to terrestrial ecological resources from construction and operation of fossil plants are different in kind and magnitude than impacts from the various hydropower alternatives. Most construction of fossil plants occurs on land, and the area needed for facilities, storage piles, waste disposal, access, and utilities is much larger. Construction-related mitigative measures to control erosion, sedimentation, and spills at hydroelectric facilities can be employed to minimize terrestrial impacts at fossil plants. Unless the fossil plant creates a large cooling lake, losses of terrestrial habitat may still be relatively small in a regional context, although larger than those for upgrading or retrofitting existing reservoirs for hydropower production.

Storage and disposal of large volumes of solid waste uses large land areas at coal-fired plants, sometimes including valuable habitats such as wetlands and floodplains. Inadequately controlled leachates from both coal and ash piles can degrade adjacent wetlands and soils in riparian zones and may have long-term toxic effects on terrestrial biota. In addition, potentially significant habitat losses are associated with the fuel cycle for coal-fired plants over larger geographic areas. Coal mining and transportation can seriously affect large areas of terrestrial habitat (Dvorak et al. 1978). Acid deposition and carbon dioxide releases from fossil plants may also cause long-term impacts to terrestrial ecosystems in large areas.

3.3.5 Recreation

The continued reliance on fossil fuels as the country's major source of electrical generating power could have significant impacts on recreational pursuits in some areas. Air quality impacts from coal combustion (in combination with emissions from transportation) already affect the use of recreation resources by people with respiratory problems in some major U.S. cities during air inver- sion episodes. Acid deposition from coal combustion is believed to have affected fishing in lakes in New England and in some other areas of the country. Acid mine drainage from coal mines can affect the fishing, whitewater canoeing and kayaking, boating, swimming, hiking, and general aesthetic quality of streams in Appalachia and elsewhere. Surface mining of coal can disturb recreational opportunities such as hiking, hunting, and nature observation throughout the United States, although some reclaimed sites may enhance these same recreational resources.

Possible effects on recreation resources that may accompany increased concentrations of greenhouse gases in the atmosphere include changed regional precipitation quantities and regimes, more frequent and more severe air inversions, increased or reduced reservoir capacities, more frequent and more severe major storms in coastal areas, sea level rise, altered wildlife habitat, and changed migration paths and times for wildlife. All of these will potentially affect almost any outdoor recreational pursuit.

Power generation using gas and oil results in some water quality impacts near refineries and drilling rigs and occasional oil spills onshore or offshore from tankers, rigs, or pipelines. All of these could affect recreational activities such as fishing, boating, swimming, and nature observation. Refineries are frequently viewed as noxious facilities (with both visual and olfactory impacts) incompatible with recreational resources. Pipelines can detract from aesthetic enjoyment of recreation where they occur. Increased use of gas and oil could mean drilling and other exploration and production activities in wildlife refuges and fragile offshore locations, with potential negative effects on recreational pursuits.

Natural gas desulfurization facilities, commonly located near the drilling rigs, could produce visual, auditory, and olfactory impacts in some relatively pristine environments in the western United States where the gas is found. Hiking, hunting, and nature observation could be affected.

3.3.6 Energy Security Benefits

Coal and domestic gas supplies provide a relatively secure energy resource. Coal is considered the most abundant nonrenewable energy resource in the United States. Fossil-fueled plants are highly reliable, although they may be affected by severe weather conditions such as droughts (which can make cooling less efficient and power production more expensive). Fossil-fueled thermal electric plants are not efficient for following daily demand cycles, but the use of gas turbine plants (which can respond quickly to changing loads but are less efficient) and pumped storage hydroelectric projects can mitigate this inefficiency. Fossil-fueled plants can have major environmental impacts, including air emissions of regional and global concern and consumptive water use, which can limit development of new plants at many sites.

Unlike coal and gas supplies, oil supplies in the United States are highly dependent on foreign sources. Power generation using oil is detrimental to energy security since it consumes a resource that is provided largely by foreign suppliers and has other important uses such as transportation and chemical production.

3.4 IMPACTS OF HYDROPOWER DEVELOPMENT AT NEW DAMS

The NES reference case predicts there will be increases in hydroelectric development at sites other than those affected by the DOE initiative. This scenario includes development both at existing dams and at sites requiring new dams or diversions. Impacts of development at existing dams would be the same as described in Sects. 3.1 and 3.2; impacts of hydroelectric development at new dams are discussed here.

New hydroelectric sites are expected to include mostly small dams, since few sites remain for new large-scale hydropower production. In a study of the potential development of small (less than 100-MW capacity) projects at new dams, FERC (1988a) predicted that, under favorable economic conditions and existing environmental constraints, approximately 180 new dams could be developed, with a capacity of about 1.5 GW. The national and regional environmental impacts of this development have been discussed in FERC (1988a).

3.4.1 Water Resources

The impacts of retrofitting dams to develop new hydropower (Sect. 3.2.1) are also encountered by projects at new dams. In addition, the impacts of constructing and operating dams, diversions, and reservoirs occur at new sites. In regions where many hydropower facilities exist, cumulative impacts to water resources, such as extensive water quality and aquatic habitat degradation, can occur.

Hydroelectric development at new sites usually involves substantial changes to local water flows and water quality. Simple diversion projects without storage capacity reduce water flows within the reach that is diverted but do not alter flow patterns downstream of the project. Larger projects that include storage reservoirs can change the seasonal flow patterns downstream of the plant—for example, by reducing flows during naturally high flow periods (by storing water) and augmenting flows during naturally low flow periods (by releasing stored water). Projects with storage can also induce daily flow cycles by releasing more water for generation during periods of daily peak demands. The impacts of reduced flows in a diverted reach can be mitigated by releasing more water (which cannot be used for generation) through the reach. The impacts of daily flow fluctuations can be mitigated by using a re-regulation structure to even out flows or by prohibiting such cycles.

New dams often alter water temperatures of the affected streams. Diversion projects reduce the flow in a stream reach, which allows greater solar heating and higher temperatures in the diverted reach. Projects with storage can have complex effects on temperature that depend on the size and shape of the reservoir, local climate, and flow release patterns.

New reservoirs can substantially alter water chemistry in the reservoir and downstream of it. Impacts of reservoir operations on DO are discussed in Sect. 3.2.1. In addition, concentrations of nutrients (phosphorus and nitrogen) and algae can be altered within reservoirs. During the early years of a reservoir's operation, concentrations of nutrients and organic carbon are increased by the decay of the plants that were submerged.

3.4.2 Air Quality

New hydroelectric dams involve few air quality concerns. Fugitive dust and vehicle emissions occur during construction, but these emissions are usually short-term, local, and minor. No significant emissions typically result from operation of a hydroelectric plant.

3.4.3 Aquatic Ecosystems

Construction of new dams for hydropower development would cause impacts similar to those described in Sect. 3.2.3, except at a larger scale. The large amount of civil work associated with constructing the dam, powerhouse, penstock, roads, and other new facilities would result in greater risk of water quality degradation from soil erosion and spills. In addition, creation of an impoundment would eliminate free-flowing stream habitat behind the dam.

Hydroelectricity generation at a new dam may cause major changes in the timing and magnitude of stream flows below the reservoir, which in turn could significantly affect tailwater biota that were formerly adapted to a natural seasonal cycle of flows and temperature conditions (Loar and Sale 1981, Sale 1985). The severity of these impacts depends on a number of factors, including the size (storage capacity) of the new reservoir and the length of the diverted reach. Turbine-passage mortality (Sect. 3.2.3) could also affect fish populations in the stream.

A new hydroelectric dam will create a barrier to upstream movement of fish that did not previously exist. This is a potential problem at any site but particularly where the stream supports runs of anadromous species (i.e., coastal and Great Lakes areas). Upstream fish passage facilities may be required to mitigate these effects (Hildebrand 1980a).

Compared with the other hydropower alternatives considered in this document, the chief additional impacts of development of new dams are loss of stream habitat (both above and below the dam) and the barrier to movements of fish represented by the new dam. These impacts are among the most difficult to mitigate and, from the standpoint of aquatic resources, may be the most serious impacts of new hydropower development.

3.4.4 Riparian and Terrestrial Ecosystems

Construction of new dams for hydropower development would cause impacts similar to, but more extensive than, those described in Sect. 3.2.4. The disturbance associated with constructing the dam, powerhouse, penstock, roads, and other facilities would result in greater risk of habitat damage through soil erosion and spills. In addition, creation of a new impoundment could eliminate or alter terrestrial and riparian vegetation associated with free-flowing streams through inundation or flow changes.

Hydroelectric generation at a new dam may cause major changes in streamflows below the reservoir, which in turn could significantly impact tailwater wetlands and emergent vegetation. Projects that produce electricity by diverting water through penstocks for significant distances may produce losses or undesirable changes to riparian zones along dewatered reaches (Kondolf et al. 1988). Such damage is particularly serious in semiarid or arid regions (including much of California and the southwestern United States) where streamside vegetation is particularly important ecologically. In such regions the riparian zone may provide the only forest habitat.

3.4.5 Recreation

The creation of hydropower facilities at new dams involves a host of impacts to recreation resources but also offers new recreational opportunities. The impoundment of free-flowing streams necessarily means the conversion of aquatic habitat from flowing water to slack or slow-flowing water. It also can entail major reductions in flows in stream reaches.

Construction of dams, powerhouses, penstocks, intake structures, power lines, access roads, etc., can have severe negative impacts on fishing, swimming, hiking, and hunting. These effects should be short-lived in the East, but in the drier West, where vegetation takes longer to recover, the effects of hydropower development can be visible for years, affecting the aesthetics of many recreational pursuits. Development of high-head facilities will most likely cause more and longer-lasting construction impacts than will the development of low-head facilities.

Many of the normal measures to protect against erosion and other disturbances common to licensed construction activities will be adequate to protect recreational resources from the worst construction impacts, but heavy equipment and major land-use change will cause severe effects on most recreational pursuits during the construction process. Following the measures outlined in Sect. 3.1.1.1 should ensure that long-term impacts from construction activities are minimized.

Blockage of fish migration can seriously affect the nature of the fishing resource and the types of fishing opportunities available. Partial dewatering can cause changes in riparian vegetation and the wildlife that it supports, inducing major changes to hunting, fishing, hiking, swimming, picnicking, and nature observation. Increased access through new roads can mean visitation by a wider variety of users than that of the preconstruction site. Submergence of terrestrial habitats by reservoirs has obvious long-term impacts on displaced recreational land uses (e.g., hunting, hiking, and nature observation could be replaced by fishing, boating, and swimming). Downstream of new hydropower facilities, long-term impacts could affect fishing, hiking, and boating.

Many impacts, including submerged lands, changed riparian vegetation, lost aquatic habitats, expanses of calm water, and partially dewatered streams, are irreversible as long as the facilities are in place.

3.4.6 Energy Security Benefits

The energy security benefits of hydroelectric development at new sites are similar to those at retrofitted dams (Sect. 3.2.6). However, the additional environmental impacts of developing new dams add uncertainty to the question of how much of this resource can be developed; environmental concerns would prevent the development of some new hydroelectric sites. Since few good sites remain for major new hydroelectric development, development at new sites can be expected to be less reliable (i.e., more vulnerable to short-term fluctuations in streamflows) and smaller than much of the existing hydropower resource.

4. CONCLUSIONS

DOE's proposed initiative to upgrade existing power plants and to retrofit dams to generate new hydropower is expected to increase capacity by about 16 GW. This capacity could replace about 9 GW of fossil-fueled capacity or other electric power resources.

Hydropower plant upgrades can provide additional power with minimal environmental impacts. Upgrades that involve only efficiency increases are expected to have negligible impacts and to provide benefits such as reduced turbine mortality of fish and the opportunity to install aerating turbines. Upgrades that involve increasing the flow or head used by a plant (e.g., by adding turbines or raising the elevation of a reservoir) have greater potential to cause changes in the environment, such as changes in downstream flows and water quality and in the terrestrial environment near the reservoir. Mitigation techniques are available to minimize or eliminate most impacts of upgrade projects.

Retrofitting dams to generate new hydropower is attractive because most impacts of hydropower development have already occurred as a result of construction and operation of the dam. However, site-specific impacts can still result, such as reductions in aeration at the dam, changes in reservoir and tailwater water quality resulting from changes in release elevation, turbine entrainment and mortality of fish, and slightly increased flood risks. Most of these impacts can be avoided or reduced by using common mitigation techniques. Site-specific evaluation of project impacts during the FERC licensing process is designed to ensure that projects include adequate mitigation and that impacts are acceptable.

Hydropower developed under the proposed DOE initiative is most likely to replace fossil-fueled power generation. The use of fossil fuels for power generation has many potential significant environmental impacts. Coal- and oil-fired generation is an important contributor to local and regional air quality problems such as acid deposition. The extraction, transportation, and refining or cleaning of oil and coal involve many impacts such as oil spills, the impacts of coal mining, and solid waste disposal. Generation using natural gas causes fewer air emissions, but all fossil fuel combustion emits large quantities of carbon dioxide, contributing to the global greenhouse gas problem.

The development of hydropower at new dams could also be replaced by some of the power developed under the DOE initiative. Hydropower development at new dams involves some local, regional, and long-term impacts that would not result from development at existing dams, but generally does not cause impacts of global concern.

The hydropower that would be produced as a result of the DOE initiative would replace only a small part of the growth in U.S. fossil-fueled generation expected by 2030. The estimated 5.1 GW of upgrade capacity and 10.6 GW of retrofit capacity would replace approximately 1.2% of the increase in fossil-fueled capacity between 1990 and 2030 predicted under the NES reference case. However, there is a great need to reduce the impacts of fossil generation such as acid deposition, greenhouse gas emissions, and consumption of petroleum reserves. The proposed hydropower initiative could reduce sulfur emissions by replacing conventional coal-fired plants but would result in only very small reductions in emissions of nitrous oxides, carbon dioxide, and particulates. The development of hydropower at sites where impacts would be minor is an important and beneficial way to reduce fossil generation.

5. REFERENCES

Bohac, C. E., E. D. Harshbarger, and A. R. Lewis. 1983. Techniques for reaeration of hydropower releases. Technical report E-83-5. Prepared by the Tennessee Valley Authority for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Cada, G. F. 1990. Assessing fish mortality rates. Hydro Rev. 9(1):52-60.

Cada, G. F., K. D. Kumar, J. A. Solomon, and S. G. Hildebrand. 1983. An analysis of dissolved oxygen concentrations in tail waters of hydroelectric dams and the implications for small-scale hydropower development. Water Resour. Res. 19:1043-1048.

Coutant, C. C. 1981. A critical review of aquatic ecological effects of power plant cooling. Office of Health and Environmental Research, U.S. Department of Energy, Washington, D.C. 238 pp.

DOE (U.S. Department of Energy). 1989. Clean Coal Technology Demonstration Program, final programmatic environmental impact statement. DOE/EIS-0146. U.S. Department of Energy, Washington, D.C.

DOE (U.S. Department of Energy). 1990a. Review of impediments in hydroelectric licensing and development in support of the National Energy Strategy. Unpublished report. DOE Office of Utility Technologies. Washington, D.C.

DOE (U.S. Department of Energy). 1990b. The Potential of Renewable Energy: An Interlaboratory White Paper. DE90000322. U.S. Department of Energy, Washington, D.C.

Dvorak, A. J., et al. 1978. Impacts of coal-fired power plants on fish, wildlife, and their habitats. Prepared for the U.S. Nuclear Regulatory Commission by Argonne National Laboratory, Argonne, Illinois. 221 pp.

EPRI (Electric Power Research Institute). 1988. Proceedings: Fish protection at steam and hydroelectric power plants. EPRI CS/EA/AP-5663-SR. Electric Power Research Institute, Palo Alto, California.

FERC (Federal Energy Regulatory Commission). 1988a. PURPA benefits at new dams and diversions, final staff report evaluating environmental and economic effects. FERC Docket no. EL87-9. Federal Energy Regulatory Commission, Washington, D.C.

FERC (Federal Energy Regulatory Commission). 1988b. Hydroelectric development in the upper Ohio River basin, final environmental impact statement. FERC/FEIS-0051. Federal Energy Regulatory Commission, Washington, D.C.

Hildebrand, S. G. (ed.). 1980a. Analysis of environmental issues related to small-scale hydroelectric development. II. Design considerations for passing fish upstream around dams. ORNL/TM-7396. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 78 pp.

Hildebrand, S. G. (ed.). 1980b. Analysis of environmental issues related to small-scale hydroelectric development. III. Water level fluctuation. ORNL/TM-7453. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 78 pp. (plus appendix).

Hunsaker, D. B., Jr., R. B. McLean, W. M. Willis, G. F. Cada, E. J. Liebsch, R. L. Graham, C. T. Garten, C. T. Hunsaker, A. W. Campbell, G. Marland, and R. L. Miller. 1990. Assessing the potential environmental impacts of proposed rules affecting future electric power generation in the United States. ORNL/TM-11301. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 42 pp. (plus appendices).

Kondolf, G. M., J. W. Webb, M. J. Sale, and T. Felando. 1988. Basic hydrologic studies for assessing impacts of flow diversions on riparian vegetation: Examples from streams of the eastern Sierra Nevada, California, USA. Environ. Manage. 11:757-769.

Langford, T. E. 1983. Electricity generation and the ecology of natural waters. Liverpool University Press, Liverpool, England. 342 pp.

Loar, J. M. and M. J. Sale. 1981. Analysis of environmental issues related to small-scle hydroelectric development: V. Instream flow needs for fishery resources. ORNL/TM-7861. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 123 pp.

Malanchuk, J. L., and R. S. Turner. 1987. Effects on aquatic systems. Chapter 8. IN Effects of Acidic Deposition, Interim Assessment of the National Acid Precipitation Assessment Program, Vol. IV. National Acid Precipitation Assessment Program, Washington, D.C.

Miller, T. J., W. S. Creal, and J. D. Suppnick. 1985. Dissolved oxygen and sediment contamination considerations in refurbishment of defunct hydropower sites: A case study on the Kalamazoo River, Michigan. pp. 114-120. IN F. W. Olson, R. G. White, and R. H. Hamre (eds.), Proceedings for the Symposium on Small Hydropower and Fisheries. American Fisheries Society, Bethesda, Maryland. 497 pp.

NAPAP (National Acid Precipitation Assessment Program). 1990. Acidic Deposition State of Science and Technology, Vol. II: Aquatic Processes and Effects. National Acid Precipitation Assessment Program, Washington, D.C.

Norwegian Hydrodynamics Laboratories. 1984. Supersaturation of dissolved air in the waterways of hydroelectric power plants. Report no. NHL 2 84075. Norwegian Hydrodynamics Laboratories, Trondheim, Norway.

Placet, M., D. G. Streets, and E. R. Williams. 1986. Environmental trends associated with the Fifth National Energy Plan. ANL/EES-TM-323. Argonne National Laboratory, Argonne, Illinois.

Railsback, S. F., J. M. Bownds, M. J. Sale, M. M. Stevens, and G. H. Taylor. 1990. Aeration at navigation dams in the upper Ohio River basin. Environ. Eng. 116(2):361-375.

Ruggles, C. P. and N. H. Collins. 1981. Fish mortality as a function of the hydraulic properties of turbines. Report G 144. Canadian Electrical Association, Montreal, Quebec, Canada.

Sale, M. J. 1985. Aquatic ecosystem response to flow modification: An overview of the issues. pp. 25-31. IN F. W. Olson, R. G. White, and R. H. Hamre (eds.), Proceedings of the Symposium on Small Hydropower and Fisheries. American Fisheries Society, Bethesda, Maryland. 497 pp.

Sale, M. J., S. F. Railsback, S. Y. Chang, C. C. Coutant, R. E. Spath, and G. H. Taylor. 1989. Balancing hydropower development in the Ohio River basin. pp. 886-896. IN A. J. Eberhardt (ed.), Waterpower '89, Proceedings of an International Conference on Hydropower, Vol. 2, American Society of Civil Engineers, New York.

Schmitt, R. W., and L. Varga. 1988. Considerations for retrofitting large dams for hydropower. pp. 159-163. IN B. W. Clowes (ed.), Waterpower '87, Proceedings. American Society of Civil Engineers, New York.

Thene, J. R., H. G. Stefan, and E. I. Daniil. 1989. Low-head hydropower impacts on stream dissolved oxygen. Water Resour. Bull. 25(6):1189-1198.

Turbak, S. C., D. R. Reichle, and C. R. Shriner. 1981. Analysis of environmental issues related to small-scale hydroelectric development: IV. Fish mortality resulting from turbine passage. ORNL/TM-7521. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 112 pp.

USEPA (U.S. Environmental Protection Agency). 1986. Ambient water quality criteria for dissolved oxygen. EPA 440/5-86-003. Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C.

Waggoner, P. E. (ed.). 1990. Climate Change and U.S. Water Resources: Report of the American Association for the Advancement of Science Panel on Climatic Variability, Climate Change, and the Management of U.S. Water Resources. John Wiley, New York. 496 pp.

Wilhelms, S. C., M. L. Schneider, and S. E. Howington. 1987. Improvement of hydropower release dissolved oxygen with turbine venting. Technical report E-87-3. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Wyolke, R. E., G. R. Bouck, and R. K. Stroud. 1975. Gas-bubble disease: a review in relation to modern energy production. pp. 239-265. IN S. B. Saila (ed.), Fisheries and Energy Production: A Symposium. Lexington Books, Lexington, Massachusetts. 300 pp.

ORNL/TM-11673

INTERNAL DISTRIBUTION

1. L. D. Bates
2. G. F. Cada
3. J. H. Cushman
4. M. P. Farrell
5. D. E. Fowler
6. C. W. Gehrs
7. S. G. Hildebrand
8. A. P. Malinauskas
9. C. H. Petrich

10.-19. S. F. Railsback

20. D. E. Reichle

21.-25. M. J. Sale

26. J. A. Shaakir-Ali
27. D. S. Shriner
28. S. H. Stow
29. R. I. Van Hook
30. J. A. Watts
31. J. W. Webb
32. Central Research Library

33.-47. ESD Library

48.-49. Laboratory Records Department

50. Laboratory Records, ORNL-RC
51. ORNL Patent Section
52. ORNL Y-12 Technical Library

EXTERNAL DISTRIBUTION

53. R. H. Ball, U. S. Department of Energy, 1000 Independence Avenue, SW, PE-70, Room 4G-036, Washington, DC 20585

54. P. A. M. Brookshier, Idaho Operations Office, U.S. Department of Energy, 785 DOE Place, Idaho Falls, ID 83402

55. P. Carrier, U.S. Department of Energy, 1000 Independence Avenue, SW, PE-51, Room 7H-075, Washington, DC 20585

56. J. V. Flynn, U.S. Department of Energy, 1000 Independence Avenue, SW, CE-121, Room 5H-095, Washington, DC 20585

57. J. F. Franklin, Bloedel Professor of Ecosystem Analysis, College of Forest Resources, University of Washington, Anderson Hall (AR-10), Seattle, WA 98195

58. G. M. Hornberger, Professor, Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903

59. G. Y. Jordy, Director, Office of Program Analysis, Office of Energy Research, ER-30, G-226, U.S. Department of Energy, Washington, DC 20545

60. R. Kessler, U.S. Department of Energy, 1000 Independence Avenue, SW, CE-121, Room 5H-095, Washington, DC 20585

61. G. E. Likens, Director, The New York Botanical Garden, Institute of Ecosystem Studies, The Mary Flagler Cary Aboretum, Box AB, Millbrook, NY 12545

62. R. R. Loose, U.S. Department of Energy, 1000 Independence Avenue, SW, CE-121, Room 5H-095, Washington, DC 20585

63. H. M. McCammon, Director, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, ER-75, U.S. Department of Energy, Washington, DC 20545

64. D. Moses, Office of Environmental Analysis, U.S. Department of Energy, 1000 Independence Avenue, SW, PE-70, Room 4G-036, Washington, DC 20585

65. R. H. Olsen, Vice President for Research, University of Michigan, 6643 Medical Science Building II, Ann Arbor, MI 48109-0620

66. G. L. Sommers, Idaho National Engineering Laboratory, P.O. Box 1625, MS-3526, Idaho Falls, ID 83415

67. E. R. Williams, U.S. Department of Energy, 1000 Independence Avenue, SW, PE-70, Room 4G-036, Washington, DC 20585

68. F. J. Wobber, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, ER-75, U.S. Department of Energy, Washington, DC 20585

69. Office of Assistant Manager for Energy Research and Development, Oak Ridge Operations, P.O. Box 2001, U.S. Department of Energy, Oak Ridge, TN 37831-8600

70.-79. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831