Hydropower: From Rivers to Oceans

With rising concerns of global warming and GHG emissions, the search for renewable energy sources has become more important than ever. Certainly, the human race has made considerable progress for such discoveries; from solar power to wind power to nuclear power- just to name a few - and the field of renewable energies is only advancing from here. Among viable energy sources lies hydropower, which despite implications of renewability and zero GHG emissions, lies a deep history of immense local environmental damage associated with traditional hydropower, which massively outweighs the surface-level benefits. Such environmental implications have made hydropower a controversial area in renewable energy topics, with traditional methods becoming more and more frowned upon by the general public. Despite its long history of environmental damage, recent technological developments have opened up a path for more sustainable alternatives and solutions, which despite recurring environmental impacts, offers a more promising renewable energy source.

Historical Background

The concept of hydropower itself is nothing new in human history, yet the commonly known conventional methods of dams and reservoirs rose in popularity during the late 19th and into the 20th century, a time where U.S. migration into the West saw significant movement with particular emphasis on agriculture and land expansion.[1] However, one particular problem of note was the arid climate of the region, a deterrent to the aforementioned hopes of agricultural land use. Suddenly, water was becoming even more of a scarce resource in a field where it was already in high demand. To combat the water problem, irrigation innovations and projects were created, including the highly common development of dams. In addition to agricultural irrigation, these dams also provided water supplies necessary to human development, as well as

[1] G. Di Baldassarre et al. (2021)

electricity in the form of hydroelectric power, among other things. Not only did this benefit the farming industry, but it also helped settlements flourish in otherwise unsurvivable conditions, providing basic utilities and economic growth.[2] In this period of dam development, hydroelectric power provided from dams accounted for nearly 40% of energy consumption in the U.S.,[3] and it is hard not to see why it was so popular. Compared to other renewable energy sources, hydropower was considered one of the least technical, the most conventional, and the easiest to implement at the time.[4] Economies grew as dams started to become the centerpiece of industrial and agricultural communities, following a natural supply-and-demand cycle between water sources and population needs of the time (Fig 1).

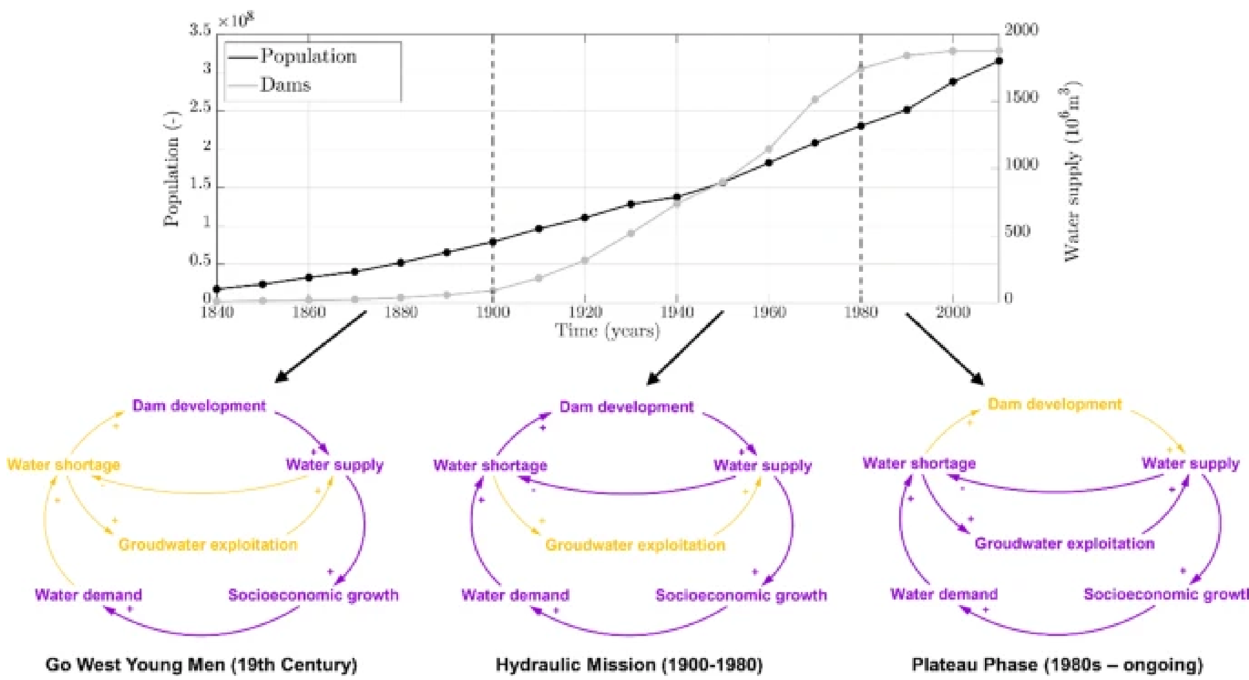

Figure 1. Temporal trends between human populations and dam development (Source: G. Di Baldasarre 2021)

[2] B.D. Richter, S. Postel et al. (2010)
[3] E. Moran et al. (2018)
[4] P. Gleick (1992)

Traditional Consequences

Eventually, dam development started to level off in the late 20th century, with varying concerns starting to rise throughout the nation.[5] Development concerns rose when ideal sites for damming were starting to decrease in number, and development started to encroach onto unsuitable lands. Practical concerns called into question the need for such structures, as they symbolized a brute-force infrastructural solution to combat environmental limitations. This was made increasingly clear with a growing recognition of global climate change; deteriorating environmental conditions only served to emphasize the dry regions of the West, which despite agricultural success, still faced high water demands. As said demands started to grow, so did water supplies begin to grow, and thus did water use, further prompting higher demands (Fig 2).

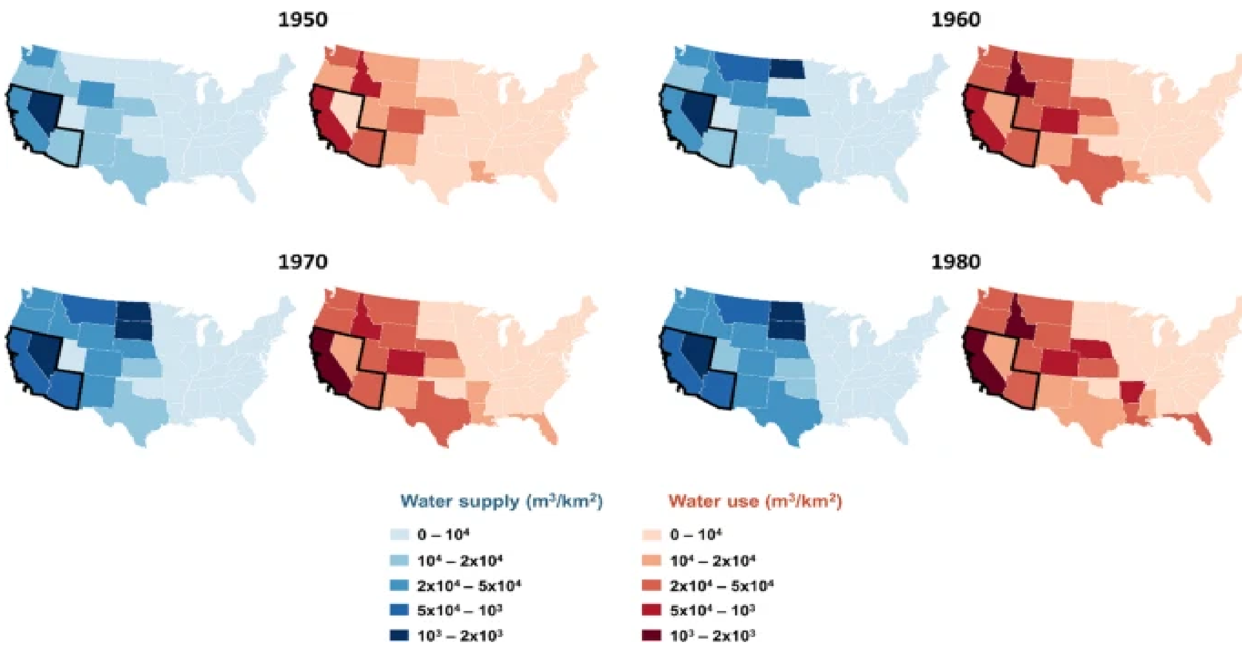

Figure 2. Temporal relationship between water supply and water use in the West (Source: G. Di Baldasarre 2021)

The brute-force nature of dams in the West was suddenly becoming clear - cities that have thrived on such projects were caught in this vicious cycle of use-and-demand and were starting to face water shortages. Equity concerns shed light on displaced communities who previously

[5] G. Di Baldassarre et al. (2021)

depended on ecological water sources for their social, cultural, and spiritual well-being.[6] The act of blocking free-flowing rivers disrupted the livelihood of downstream river communities, disrupting sources of irrigation and fisheries. Contractors and financiers of dams would profit off of the physical displacement of said communities, contributing to global income inequalities. Economic concerns saw financial costs of construction skyrocketing, and as ideal sites were already all being exploited, the costs slowly started to outweigh the benefits. Maintenance costs were usually met half-heartedly or even ignored, contributing to dilapidation and increased flood risk.[7] Power concerns called into question the effectiveness of hydropower in generating electricity. Contribution to national energy consumption declined from a staggering 40% to a mere 6%, while other renewable energy sources - wind, solar, nuclear, etc. - slowly began to overtake hydropower in terms of popularity and effectiveness.[8]

By far the most outspoken concern of the time was the immense environmental impacts of hydroelectric dams. Despite surface-level impressions of being a renewable energy source, hydropower was anything but; local ecological degradation massively outweighed the benefit of renewable energy. Artificial reservoirs saw increased evaporative losses which usually factored into resource consumption, built-up sedimentation took up potential storage in addition to increasing the risk of flooding, seepage losses through porous natural material kept capacities from truly filling up; and these were just the geophysical impacts.[9] Ecological impacts happened on a much larger scale, the most obvious of which is the displacement of local fauna. With water sources no longer free-flowing, fish migratory patterns were disrupted and habitats were destroyed, affecting populations and by association, affecting overall biodiversity. Reduced

[6] B.D. Richter, S. Postel et al. (2010)
[7] E. Moran et al. (2018)
[8] idib.
[9] P. Gleick (1992)

freshwater discharge reduced the natural movement of nutrients, affecting local food chains that ecosystems would thrive on. Conversion of running water to still water in reservoirs created temperature and oxygen conditions unsuitable for the survival of fauna, and encouragement of fostering exotic species only served to further displace indigeneous populations - and the list goes on.[10] Certainly, amidst promises of renewable energy, hydropower failed to deliver in the contemporary age; the costs were simply too great to justify the single benefit.

Solutions: Modification

The shift in the general consensus away from the popularity of dams have offered up a variety of solutions in hopes of attaining the sustainability of hydroelectric power without the environmental headaches that were associated with traditional methods. The first of these solutions was direct involvement into the infrastructure itself, ranging from simple modifications to complete demolition.

Common modification techniques involved attempts to mitigate the biodiversity impacts of large dams, specifically ensuring that indigineous populations remained relatively undisrupted. Fish passages provided a means of movement for migratory patterns, yet these were rarely effective. Mitigation efforts through fish ladders were considered successful when 90-100% of migrating fish were allowed for - the average efficiency was around 40%, with some sites even reporting a 0% efficiency.[11] Other methods included adjustment of flow rates and turbine speeds, while sediment management usually involved sluicing, bypasses, and even manual excavation.[12]

Although intuitive at first, choosing ideal dams for modification were planning headaches; a number of conditions and circumstances had to be met before even prompting

[10] D. McAllister et al. (2001)
[11] M.J. Noonan, J.W.A. Grant, C.D. Jackson (2012)
[12] C. Moncrieff (2017)

re-optimization of dams, with a good number of considerations residing beyond the infrastructure itself (Figure 3).[13] Full dam removal was heavily preferred, as it skipped the convoluted and costly nature of modification, while guaranteeing full river restoration.

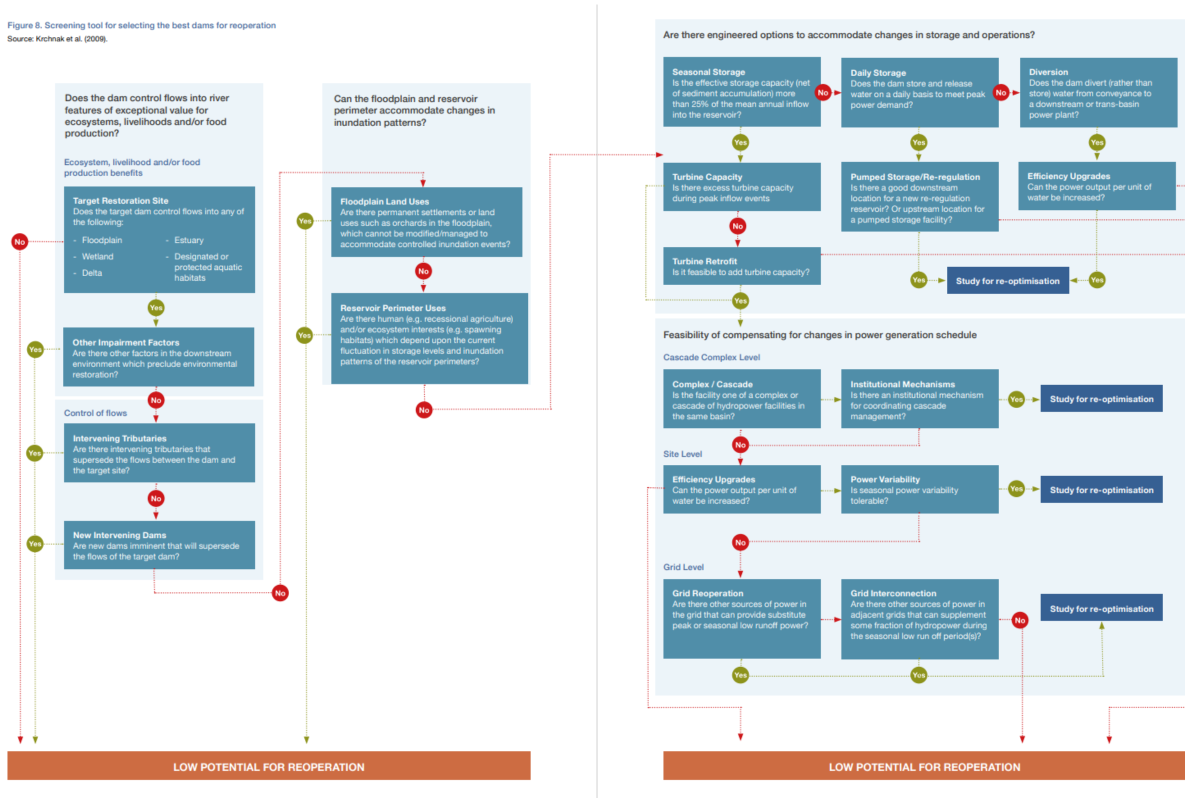

Figure 3. Screening tool used for re-operation considerations (Source: C. Moncrieff 2017)

A removal of two dams on Elwha River in Washington state not only fully opened up fish migratory patterns, but also restored sacred sites originally belonging to the indigenous Lower Elwha Klallam tribe.[14] Certainly, full dam removal is becoming ever more popular in the contemporary 21st century. American Rivers, an organization dedicated to the conservation and restoration of U.S. rivers, has stated that optimal river restoration included removal of dams, and has contributed to the removal of more than 200 dams nationwide. Although a far cry from the

[13] C. Moncrieff (2017)
[14] R. Cho (2011)

massive number of 90,000 nationwide dams, general consensus is slowly starting to favor such projects, with indicators in the social and political scene.[15]

Although overlooked and underappreciated, political modifications surrounding infrastructure are just as important with respect to dam modification. American Rivers has projected that without important bills promoting and incentivizing dam removal (e.g. the Infrastructure Investment and Jobs Act), nation-wide dam removal would be nothing more than a pipedream.[16] Interests between local communities and private industries were usually polarized when it came to decision-making, giving responsibility to federal regulations and policies. Governance solutions weren't novel in the least, but were certainly effective; stronger emphasis and enforcement of Environmental Impact Assessments and Social Impact Assessments ensured that such assessments were accurately and actually carried out, providing full disclosure and transparency, guaranteeing that stakeholders' interests were completely heard. Rigorous standards would prevent the building of obsolete dams onto unideal sites, as well as improving modification designs, if dam removal was not a viable option.[17]

With dam modification gaining popularity in the late 20th century into the 21ist century, promises of renewable hydroelectric power still remained in the air. Although modification worked towards ecological and social restoration, it did not provide any value for renewable energy itself; a concern that is only growing with exacerbating climate change problems. However, latest developments have made possible the innovations of tidal and wave energy, which despite the recent nature of said forms of hydropower, promises a successful renewable energy source.

---

[15] American Rivers (2022)
[16] idib.
[17] E. Moran et al. (2018)

Solutions: Alternatives

Although differentiated by slight nuances, tidal and wave power are referred to relatively interchangeably. Both forms of power depend on the oscillating movement of ocean waves, capturing it in order to effectively rotate turbines connected to generators, not unlike wind turbines or even traditional hydroelectric turbines.[18] Although the principle remains largely the same, tidal power has proven to be a more effective renewable energy source than hydroelectric dams. Ocean waves provide much more intensity and force needed to create much more significant renewable energy, almost to the point where tidal power has been likened closely to wind power rather than traditional hydropower. Even in this sense does tidal power offer notable competition; the attributed oscillating movement is more persistent and concentrated compared to the popular wind power. [19]

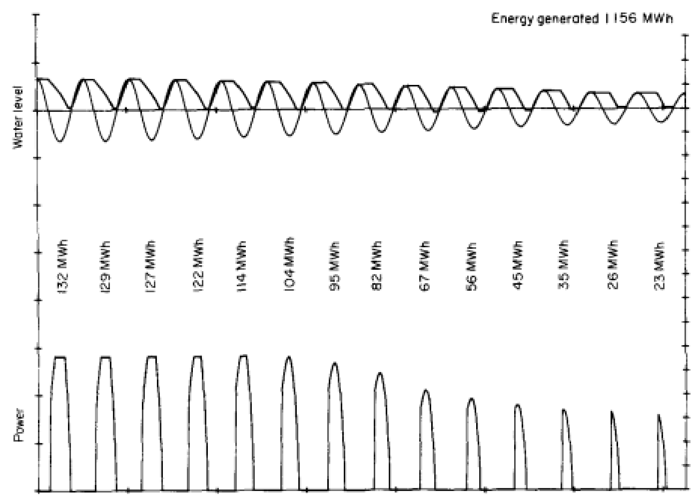

Figure 4. Relationship between ebb-and-flow of ocean waves and energy output (Source: C. Baker 2003)

With tidal power being a relatively fresh development, the impacts of said energy are still largely unknown, due to a lack of available sites and significant existing data.[20] To date, public concerns surrounding tidal power have mostly been economic and practical in nature; expensive

[18] C. Baker (2003)
[19] J. Falnes (2007)
[20] S. Nash, A. Phoenix (2017)

financial costs, ensuring turbines were placed on ideal and optimal sites, ensuring accurate scales and efficiencies; and yet these concerns were nothing new when it came to renewable energy sources as a whole. Obvious environmental concerns involved ecological disruption and habitat disturbance, and yet these impacts are relatively meager compared to the massive implications of traditional forms. Current extensive research suggests that tidal turbines are capable of reducing velocities of incoming waves, disrupting the natural sediment transport and biogeochemical processes that would occur otherwise. Despite this claim, the same-self studies would go on to find that in the bigger picture, these impacts are relatively negligible and insignificant, although meaningful significant thresholds are still being actively explored.[21] Nevertheless, tidal power proves itself to be a more sustainable approach than its traditional counterpart.

With the field of tidal power remaining largely unexplored, approaches have been careful and holistic in nature, yet another differentiation from the brute-force nature with traditional dams. A prime example of interdisciplinary and extensive planning is the MeyGen Tidal Power Project. Located off the coast of Scotland, the project has been widely regarded as one of the most successful tidal power solutions to date, despite ongoing developments. Currently near the end of its first phase, the project has dedicated itself to careful environmental assessment and monitoring, publicly detailing any possible significant impacts on the surrounding ecosystem.[22] Listing the same aforementioned ecological disturbances as the chief environmental implications, the project has dedicated itself not just to infrastructural development, but also to active environmental monitoring (Figure 5). With the field essentially being unknown waters, so to speak, this monitoring is important to developing effective mitigation and practice measures in order to combat the known implications.[23]

[21] S. Nash, A. Phoenix (2017)
[22] Meygen Tidal Power Project
[23] idib.

Post-Installation Monitoring: MeyGen Tidal Energy Project - Phase I

Stressor	Receptor	Study Description	Design and Methods	Results	Status
Collision	Fish	Collision monitoring	Collision risk will be monitored by the installation of one or more active monitoring systems on one of more of the tidal devices.	TBC	Planned
Collision, Noise	Fish	Collision monitoring	Collection of underwater noise measurements of candidate prototype tidal turbines. Data collected will be used to validate the underwater noise modelling completed to inform the impact assessment.	TBC	Planned
Collision, Displacement	Birds	Monitoring of potential displacement and disturbance of birds	Disturbance and displacement of birds at sea will be monitored from targeted land and boat based surveys to determine any behavioral changes. Collision risk will be monitored by the installation of one or more active monitoring systems on one of more of the tidal devices; this will assist in the understanding of near field bird interaction with devices. Birds will also be fitted with geo locators and dive loggers will provide information on any correlations between the site and breeding grounds.	TBC	Planned
Noise	Marine Mammals	Acoustic monitoring of operational noise	Collection of underwater noise measurements of candidate prototype tidal turbines. Data collected will be used to validate the underwater noise modelling completed to inform the impact assessment.	TBC	Planned
Displacement	Marine Mammals	Post deployment survey to assess possible displacement	Targeted observation of marine mammals is proposed, as is acoustic monitoring of harbor porpoise using static loggers to with determining area use.	TBC	Planned

Figure 5. Sample of monitoring practices in MeyGen's Phase I (Source: MeyGen Tidal Power Project)

Discussion & Conclusion

The sustainable disparity between traditional and contemporary forms of hydropower has shown how far hydropower has come as a renewable energy source. It is important to note that while both methods may seem mechanically different, they are both relatively the same in principle; both methods rely on the movement of water to turn hydroelectric turbines. In light of this similarity, the main differences then shift towards the physical and planning circumstances surrounding each method. Environmental implications have been carefully considered and monitored in contemporary tidal power projects, and have remained relatively insignificant compared to the ecologically destructive nature of traditional dams. Beyond ecological impacts, economic concerns and equitable concerns have also greatly contributed to shifting public preference away from the historical popularity of dams, and have also contributed to the general success of contemporary solutions. Greater emphasis has been placed on public disclosure, with

EIAs and SIAs holding more power in recognition of federal responsibility, while current tidal power projects have dedicated themselves to careful and interdisciplinary monitoring.

With respect to sustainable differences, the development of tidal power itself is a testament to how innovation can not only improve renewable energy itself, but also to the circumstances surrounding it. Certainly, innovation in the field of hydropower has never been so novel. Tidal power is just but a portion of alternative solutions developed to provide a true renewable water-based energy source; current technologies have also led to the development of instream turbines designed for running freshwater sources. Once again, mechanical principles are largely the same, and yet the circumstances are different; more consideration for local environments have reduced many of the negative externalities associated with dams.[24] This kind of innovation balances the relevance between technicalities and holistic review; when considering renewable energy sources, it is just as important to consider big-picture situations, such as equitable, political, practical, etc. Contemporary hydropower has verily proved itself to be a strong contender in the field of renewable energy, and it is due to extensive and substantial review that it has come to its current position.

[24] E. Moran et al. (2018)

References

Baker, C. (2003, June 26). *Tidal Power*. Energy Policy. Retrieved from https://www.sciencedirect.com/science/article/pii/030142159190049T

Cho, R. Removing dams and restoring rivers. (2011, August 29). *State of the Planet*. https://news.climate.columbia.edu/2011/08/29/removing-dams-and-restoring-rivers/

Di Baldassarre, G., Mazzoleni, M., & Rusca, M. (2021). The legacy of large dams in the United States. *Ambio*, *50*(10), 1798–1808. https://doi.org/10.1007/s13280-021-01533-x

Falnes, J. (2007). A review of wave-energy extraction. *Marine Structures*, *20*(4), 185–201. https://doi.org/10.1016/j.marstruc.2007.09.001

Free rivers: The state of dam removal in the U. S. (2022, February 22). American Rivers. https://www.americanrivers.org/2022/02/new-report-alert-free-rivers-the-state-of-dam-removal-in-the-u-s/

Gleick, P. H. (1992). Environmental consequences of hydroelectric development: The role of facility size and type. *Energy*, *17*(8), 735–747. https://doi.org/10.1016/0360-5442(92)90116-H

Meygen Tidal Energy Project - Phase I. Tethys. (n.d.). Retrieved from https://tethys.pnnl.gov/project-sites/meygen-tidal-energy-project-phase-i

McAllister, D., & Craig, J., & Davidson, N., & Delany, S., & Seddon, M. (2001). Biodiversity Impacts of Large Dams.

https://www.researchgate.net/publication/255643683_Biodiversity_Impacts_of_Large_Dams

Moncrieff, C. (2017). *Developing Better Dams*. WWF. Retrieved from https://wwfint.awsassets.panda.org/downloads/developing_better_dams_wwf.pdf

Moran, E. F., Lopez, M. C., Moore, N., Müller, N., & Hyndman, D. W. (2018). Sustainable hydropower in the 21st century. *Proceedings of the National Academy of Sciences*, *115*(47), 11891–11898. https://doi.org/10.1073/pnas.1809426115

Nash, S., & Phoenix, A. (2017). A review of the current understanding of the hydro-environmental impacts of energy removal by tidal turbines. *Renewable and Sustainable Energy Reviews*, *80*, 648–662. https://doi.org/10.1016/j.rser.2017.05.289

Noonan, M.J., Grant, J.W.A. and Jackson, C.D. (2012), A quantitative assessment of fish passage efficiency. Fish Fish, 13: 450-464. https://doi.org/10.1111/j.1467-2979.2011.00445.x

Richter, Brian & Postel, Sandra & Carmen, Revenga & Thayer, Scudder & Bernhard, Lehner & Allegra, Churchill & Morgan, Chow. (2010). Lost in Development's Shadow: The Downstream Human Consequences of Dams. Water Alternatives. 3. https://www.water-alternatives.org/index.php/volume3/v3issue2/80-a3-2-3/file