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Rethinking Management of the Colorado River through Lake Powell, Grand Canyon, and Lake Mead

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Summary

The Colorado River crisis of 2022, when reservoir levels plummeted and the issues of “dead pool,” “outlet works,” and “Lake Powell elevations 3490 and 3525” moved from the realm of water policy nomenclature to public concern, revealed deep flaws in the current strategy of managing the watershed’s rivers and reservoirs. Much of the chaos and public concern focused on regional-scale water management. How could we avoid dead pool at Lake Powell or Lake Mead, whose stored water accounts for 60 to 80% of all the reservoir water in the basin and serves more than 30 million people?

As the water policy community now works toward a plan to keep the basin’s taps and headgates flowing in the deeply uncertain post-2026 future, the lessons of previous crises can inform a broader discussion about how to also avoid ancillary risks and achieve ancillary benefits in the Cataract Canyon/Lake Powell/Glen Canyon/Grand Canyon/Lake Mead portion of the basin. As water is released from Lake Powell to meet Upper Basin delivery requirements, as it must, how might we balance the objectives of water supply reliability and security with environmental and societal values for the Colorado River and its reservoirs? Among those values are:

- The returning river ecosystem of Cataract Canyon and the emerging splendor of Glen Canyon and its tributary canyons;
- Reservoir boating on Lake Powell and Lake Mead and river boating in Cataract, Glen, and Grand Canyons;
- Recreational warm water fisheries in Lake Powell and Lake Mead and recreational cool water fisheries immediately downstream from Glen Canyon Dam;
- Hydroelectricity produced at Glen Canyon and Hoover Dams;
- Native species, including those protected under the Endangered Species Act, that are an essential part of the Grand Canyon fish community; and,
- Sand bars used as campsites in Grand Canyon.

Some of those values were enhanced during past decades when the reservoirs were relatively full. Other values are now enhanced during the ongoing period of relatively low reservoir elevations. All those values cannot be maximized by the same amount of reservoir storage or reservoir releases, and some of them conflict with one another. Management strategies to protect those values differ, in some cases depending on whether the reservoirs are relatively full or empty.

In March 2024, we submitted a proposal to the Bureau of Reclamation’s Post-2026 National Environmental Policy Act Review process suggesting a path forward addressing some of the questions presented above. We argued that the annual release of water from Lake Powell should be disentangled from the annual accounting of Upper Basin deliveries that ensures compliance with the legal and policy agreements now being negotiated for the post-2026 era. Disentanglement would allow adoption of a more flexible approach to implementing

each year's Lake Powell release and would create an opportunity to better achieve tradeoffs balancing water supply with environmental and societal goals.

These goals might be achieved by sometimes releasing less water downstream and storing more water in Lake Powell than might be prescribed by water-supply agreements. In other years, doing the reverse and storing more water in Lake Mead might be desirable to meet environmental or societal objectives. The difference between actual releases and the negotiated agreements concerning Upper Basin deliveries could be managed in an accounting scheme balanced every few years. Flexibility in implementing each year's release from Lake Powell would make it easier to consider secondary environmental and societal goals.

In our March 2024 proposal, we suggested that the Secretary of the Interior decide every year the amount of water to be released from Lake Powell. Based on feedback to our proposal, we realize that such an approach might introduce unacceptable uncertainty to the management of water supply.

Here, we suggest an alternative approach to achieve flexibility — to re-evaluate and revise reservoir operating rules every few years. The difference between actual releases and the long-term negotiated agreement could still be managed by the same accounting scheme that we proposed earlier. Here, we suggest that the rules of reservoir release be reconsidered every few years, rather than every year. The reconsideration would be based on the status of reservoir storage, ecosystem, river resource, and other societal conditions, as well as changes in the management strategies intended to benefit various environmental and societal values, which themselves may change in the coming decades. Thus, we recommend that the philosophy of adaptive management that is the foundation of the Glen Canyon Dam Adaptive Management Program be broadly applied to water supply management of the Colorado River in Cataract Canyon/Lake Powell/Glen Canyon/Grand Canyon/Lake Mead. Adopting an adaptive approach to implementation of annual reservoir releases would not jeopardize the post-2026 agreements but would allow occasional adjustment of reservoir operating rules as the deeply uncertain future becomes better defined. An adaptive approach will be even more critical if reservoir storage plunges to very low levels for long periods, because water supply management will be severely challenged, and new environmental and societal values may emerge while others disappear. The uncertainty of the future cries out for flexibility. Locking in long-term, specific prescriptions for operations of Lake Powell and Lake Mead, as past efforts in this regard have done, would be a mistake.

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Introduction

The movement of water through much of the Colorado River, especially between Lake Powell and Lake Mead, is characterized by what has been called an "institutional hydrograph" (Fleck 2015[1]). A natural hydrograph responds to climate, and the natural ebb and flow of the Colorado River through the Grand Canyon once responded to spring snowmelt in the Rocky Mountains and summer and fall monsoon rains. Today's institutional hydrograph responds to shadows of that natural hydrograph, filtered through rules governing upstream water use and reservoir releases, the need for hydropower, and the physical infrastructure at the dams. The goal of our March 2024 proposal, and in the discussion that follows, is to explore ways in which that institutional hydrograph might be adjusted to meet water supply agreements while also benefiting some environmental and societal values.

The Cataract Canyon/Lake Powell/Glen Canyon/Grand Canyon/Lake Mead area is the heart of the Colorado River watershed. There are approximately 15 miles of natural river ecosystem between the confluence of the upper Colorado and Green Rivers and the head of Lake Powell in Cataract Canyon[2] (Webb et al., 2004[3]), and there are 255 miles of altered river ecosystem between Glen Canyon Dam and the head of Lake Mead[4], including the 15-mile Glen Canyon Dam tailwater and the 240-mile Grand Canyon[5]. At full capacity, Lake Powell is 186 miles long, but the pre-dam riverbed of the upstream 5 miles of Lake Powell, including its rapids, has re-emerged during the reservoir's ongoing low stand (DeHoff, 2022[6]).

There are significant environmental and societal values in this part of the watershed. Over the entire length of river and reservoir, at least one bank is managed by the National Park Service as Canyonlands National Park, Glen Canyon National Recreation Area, Grand Canyon National Park, and Lake Mead National Recreation Area. The Navajo Nation, Havasupai Indian Reservation, and Hualapai Indian Reservation are within or adjacent to parts of the river corridor. The Glen Canyon Dam Adaptive Management Program (GCDAMP) focuses on the area between Glen Canyon Dam and Lake Mead, and the Upper Colorado River Endangered Fish Recovery Program and the San Juan River Basin Recovery Implementation Program focus on endangered fish recovery in the inflow areas of Lake Powell and further upstream. The entire river corridor, whether river or reservoir, is one of spectacular beauty.

We are optimistic that the Basin States will reach a negotiated agreement concerning water allocation. Implementation of that agreement will require defining the annual deliveries from the Upper Basin to the Lower Basin that are accomplished by releases from Lake Powell through Glen Canyon Dam. In our March 2024 proposal, we urged flexibility in prescribing and implementing those annual deliveries. We argued that a rigid prescription defining each year's release need not be established. An accounting system could keep track of debits and credits that reflect the difference between actual releases and a negotiated long-term average delivery, and net debits or surpluses could be reconciled every few years.

In this paper, we clarify and revise aspects of our original proposal, primarily focusing on issues of the environment.

1 Fleck, J. The institutional hydrograph, Inkstain, Dec. 9, 2015; https://www.inkstain.net/2015/12/institutional-hydrology-new-mexicos-rio-grande-in-december/

2 when the reservoir is at full capacity

3 Webb, R. H., Belknap, J, and Weisheit, J. S. 2004. Cataract Canyon: a human and environmental history of the rivers in Canyonlands. University of Utah Press.

4 when reservoir is at full capacity

5 The upstream 60 miles of which between Lees Ferry and the confluence of the Little Colorado River are referred to as Marble Canyon. Here, we do not distinguish between Marble and Grand Canyons.

6 DeHoff, M. 2022. Who is in charge of the mud? *Natural Resources Journal* 62(2): 325-339.

Why flexibility is needed

Flexibility in water supply management is warranted, because there are significant uncertainties in the ability to implement deliveries from the Upper Basin in the deeply uncertain future. The longer the duration of the post-2026 Guidelines, the greater the uncertainty, because the likelihood of unusually long droughts, occasional very large inflows, reservoir sedimentation, and unexpected infrastructure issues increases with time.

The goals of environmental river management are linked to societal values

Although secondary to the concerns of a secure and reliable water supply, management of water through Cataract Canyon/Lake Powell/Glen Canyon/Grand Canyon/Lake Mead should also be implemented to benefit environmental and societal resources. There is uncertainty in codifying long-term reservoir release rules, however, because the goals of environmental and societal resource management may change in the coming decades, as will the strategies to benefit those resources. Thus, there needs to be flexibility in prescribing long-term reservoir release rules.

The values that guide management of environmental and societal resources have changed in the past and are likely to change in the future. Long-term changes in these values are difficult to anticipate, and it is difficult to develop effective management plans when those values are conflicting. Additionally, managers must decide whether to focus on improving a few resources at the expense of others or attempt to optimize a wide range of resources.

One way to think about the values that guide river management is to coarsely distinguish resources that are *relicts of the past* and from resources that are *artifacts of river regulation* (Schmidt et al,1998[7]). The former category includes resources that existed prior to dams and diversions, and the latter category includes resources that are dependent on the regulated flows provided by dams and the existence of the reservoirs themselves. As discussed below, some artifact resources benefit by relatively full reservoirs and other artifact resources benefit when reservoirs are relatively empty. It is challenging to benefit *relict*, *full-storage artifact*, and *low-storage artifact* resources with one management strategy.

Evidence that the relevant environmental and societal values change with time is provided by the 40-year history of changes in environmental and societal management goals downstream from Glen Canyon Dam in Glen and Grand Canyons. This history also demonstrates that the philosophy of focusing on a few resources or optimizing benefit to many resources has changed with time.

In the mid-1980s, the Glen Canyon Environmental Studies (GCES) focused its attention on four resources — humpback chub (*Gila cypha*), “common native fish,” and camping beaches, which are relict resources; and tailwater trout fishing which is an artifact resource (U.S. Department of the Interior. 1988[8]). In the mid-1990s, the GCDAMP identified 12 management goals for the Glen Canyon tailwater and Grand Canyon ecosystem that included relict and artifact resources, and the GCDAMP sought to identify management approaches that optimized improvement of many resources. In 2012, the GCDAMP revised these management goals as Desired Future Conditions[9] and sought to identify strategies to optimize improvement to many relict and artifact resources. In 2013, Department of the Interior leadership directed the GCDAMP to narrow its focus to native fish and sand bars, both relict resources, and artifact recreational tailwater fish communities. Today, environmental management in the Grand Canyon is primarily focused on the native fish community, especially compliance with Endangered Species Act requirements concerning humpback chub, and there is less concern about the fate of the recreational trout fishery.

7 Schmidt, J. C., Webb, R. H., Valdez, R. A., Marzolf, G. R., and Stevens, L. E. 1998. Science and values in river restoration in the Grand Canyon. *BioScience* 48(9): 735-747.

8 U.S. Department of the Interior. 1988. Glen Canyon Environmental Studies final report. Salt Lake City, Upper Colorado Region Bureau of Reclamation, 84 pp and appendices.

9 Glen Canyon Dam Adaptive Management Program DFC Ad Hoc Committee. 2012. Desired future conditions for the Colorado River ecosystem in relation to Glen Canyon Dam. January 23 review, 28 p.

Artifact resources identified in the 1980s and subsequent decades primarily resulted from a relatively full Lake Powell from which the same annual volume of relatively cool water was released. This flow regime supported the non-native, recreational rainbow trout (*Oncorhynchus mykiss*) fishery and allowed abundant non-native riparian vegetation to establish throughout Grand Canyon. Although some native fish species were extirpated from Grand Canyon due to fragmentation of migration patterns, other native fish species with restricted migration patterns took advantage of favorable flow and temperature conditions in tributaries and persisted. One of those species is the humpback chub that was listed as endangered in 1967 and maintained a modest-sized, reproducing population near the confluence with the Little Colorado River throughout the period of relatively full reservoirs.

Values, goals, and management challenges associated with a persistently low Lake Powell

Neither the GCES nor subsequent studies of the 1990s and early 2000s anticipated the environmental issues or emerging resources associated with persistent reservoir low stands of the 21st century. Some emerging resources are relicts of the past and some are artifacts of low reservoir storage, i.e., low-storage artifacts. Additionally, new management issues have arisen due to unanticipated interactions among these resources.

One of the most important changes in resource conditions involves the humpback chub that was downlisted to threatened status in 2021 primarily due to a large expansion of the population caused by warmer river temperatures released from a lower Lake Powell and due to fragmentation where the Colorado River flows into Lake Mead. Upstream migration of non-native reservoir fish into western Grand Canyon is now blocked by the violent and unnavigable Pearce Ferry Rapid that exists within the area of Lake Mead when it is full[10]. Today's population of humpback chub in Grand Canyon is more than an order of magnitude larger than it was a decade ago, and the largest aggregation of the species has shifted to western Grand Canyon (Van Haverbeke et al., 2017[11]; Rogowski et al, 2018[12]).

However, the warm reservoir releases during Lake Powell's low stand have led to a new management problem. There is increasing concern about the impact of nonnative, warm-water reservoir fish on Grand Canyon's native fish community. When Lake Powell elevations are low, reservoir fish are entrained through Glen Canyon Dam's penstocks, survive passage through the hydroelectric plant, and are released into the Glen Canyon Dam tailwater. The warm river temperature in the tailwater is favorable to survival and reproduction of the introduced reservoir fish, including smallmouth bass (*Micropterus dolomieu*), and this nonnative species might extend its range downstream into Grand Canyon. If this range expansion occurs, there is widespread fear among most fish ecologists that smallmouth bass will prey upon and reverse the recovery trajectory of humpback chub and other native species.

Other issues associated with reservoir low stands have emerged that degrade some full-storage artifact resources and benefit some relict resources. The recreational tailwater trout fishery that is dependent on cool water releases has been severely degraded by warm-water releases. New values associated with relict resources have been of increasing focus at the upstream end of Lake Powell. The "returning rapids" of lower Cataract Canyon, river landscapes of lower San Juan River canyon, and emerging iconic landscapes in Glen Canyon have received widespread attention in popular media[13].

Lower reservoir levels adversely affect traditional reservoir recreation, especially at marinas, but new forms of reservoir recreation linked to side canyon exploration have developed. The fragmentation at Pearce Ferry Rapids in Lake Mead also exists in Lake Powell. Piute Falls in the San Juan arm of Lake Powell fragments

10 The head of Lake Mead at full pool is at River Mile 240 and Pearce Ferry Rapid occurs 40 miles downstream at River Mile 280.

11 Van Haverbeke, D. R., Stone, D. M., Dodrill, M. J., Young, K. L. and Pillow, M. J. 2017. Population expansion of humpback chub in western Grand Canyon and hypothesized mechanisms. *Southwestern Naturalist* 62: 285-292..

12 Rogowski, D. L., Osterhoudt, R. J., Mohn, H. E., and Boyer, J. K. 2018. Humpback chub (Gila cypha) range expansion in the western Grand Canyon. *Western North American Naturalist* 78: 26-38..

13 Kolbert, E. 2021. The lost canyon under Lake Powell. *The New Yorker*. August 16 issue.

upstream migration of native and non-native fish from Lake Powell to the San Juan River. There is speculation that a similar waterfall, or non-navigable rapid, may form in the Colorado River arm of Lake Powell, affecting river navigation near Hite (DeHoff, 2022). These issues at the upstream end of Lake Powell affect management of Glen Canyon National Recreation Area and potentially affect the two Upper Basin endangered fish recovery programs. Few of these ecosystem issues and management challenges were anticipated in the 1980s or 1990s when the reservoirs were relatively full.

Evolving and improving river science leads to changes in best management practices

It is not only likely that the goals of environmental and societal management will change in coming decades, but the strategies recommended by scientists to benefit or protect those resources are also likely to change. Strategies are likely to shift due to improved scientific understanding and unexpected ecological feedbacks, especially in biological systems. In the mid-1990s, the inevitability of unanticipated responses to well-intentioned management was the rationale for taking an adaptive management approach to addressing ecosystem effects of Lake Powell releases. Thus, the GCDAMP was created. Today, the value of adaptive management is no less.

Scientific understanding changes, in part, because the questions asked by river scientists change. These questions not only change due to the process of scientific discovery but also due to the changing values described above. Forty years ago, the GCES asked if the existence and operations of Lake Powell and Glen Canyon Dam affected the downstream river ecosystem and resources. Although such a narrow question seems silly by today's standards, the politics of the early 1980s restricted scientists to address only this limited question. Since then, scientists have expanded the scope of their investigations and now provide insights about strategies to mitigate adverse impacts.

One example of changing foci and insights of applied river science is the history of geomorphic research concerning Grand Canyon sand bars. In the 1980s, research focused on how hydropeaking affected sandbar erosion, and the goal of that research was to define an acceptable magnitude and rate of change in hydropeaking to reduce erosion. These research findings informed limits on hydropeaking prescribed in the 1996 Record of Decision (RoD) of the Glen Canyon Dam Operations Environmental Impact Statement (U.S. Department of the Interior, 1995[14]). Subsequent research revealed that sediment-rich floods are necessary to rebuild eroded sandbars, leading to the 1996 controlled flood experiment. Monitoring of controlled flood experiments in 2004 and 2008 led to revision of existing protocols in the High Flow Experiment Protocol in May 2012[15]. Continued monitoring and research led to further revisions of the controlled flood protocol when the Long Term Experimental and Management Plan was adopted in December 2016[16] and revised in July 2024[17].

Today, emphasis is primarily placed on understanding the mass balance of sand delivered by tributary flash floods and evacuated during periods of high reservoir releases, including those associated with large annual releases. Scientists have identified the magnitude of annual releases that causes sand bar erosion and determined that the effect of those releases depends on the antecedent sand mass balance related to the preceding monsoon season (Topping et al., 2021[18]; Griffiths et

14 U.S. Department of the Interior. 1995. Operation of Glen Canyon Dam final environmental impact statement. Salt Lake City, Upper Colorado Region Bureau of Reclamation, 337 pp and appendices.

15 U. S. Department of the Interior. 2012. Record of Decision, Environmental Assessment, Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020.

16 U.S. Department of the Interior. 2016. Record of Decision for the Glen Canyon long-term experimental and management plan final environmental impact statement. Bureau of Reclamation and National Park Service, 22 p. and appendices.

17 Bureau of Reclamation. 2024. Supplement to the 2016 Glen Canyon long-term experimental and management plan Record of Decision. 18 p. and appendices.

18 Topping, D. J., Grams, P. E., Griffiths, R. E., Dean, D. J., Wright, S. A., and Unema, J. A. 2021. Self-limitation of sand storage in a bedrock-canyon river arising from the interaction of flow and grain size. Journal of Geophysical Research: Earth Surface 126: e2020JF005565.

al., 2024[19]). Annual releases from Glen Canyon Dam, defined by rigid prescriptions, might cause widespread erosion if the preceding monsoon season is dry and the prescribed annual releases are large. Rigid prescriptions of annual releases, as being considered for the post-2026 Guidelines, cannot anticipate the variability of future monsoon seasons.

As described above, the emphasis of fish management has shifted from the artifact tailwater trout community to protection of native fish from the invasion of warm water reservoir fish. However, the management strategy being implemented at this time may not be appropriate for the deeply uncertain future, because the success of the present management strategy is unknown.

Today, Reclamation is implementing a strategy of releasing some water through the river outlets to cool the temperature of water released through the penstocks so that smallmouth bass cannot reproduce in the tailwater[15]. Such a strategy unavoidably involves reduction of hydropower production. The justification of this management approach is that the invasion of smallmouth bass is in its initial stage, and the best management practice is to aggressively eradicate smallmouth bass so that the species never establishes downstream from Glen Canyon Dam. This management approach is guided by the widely influential ***invasion curve*** that links management strategy to the population status of the invading species (Fig. 1). This management framework, adopted in the Department of the Interior's Invasive Species Strategic Plan (2021[20]) summarizes the appropriate management strategies during different phases of an introduced species' invasion. The Plan explains

> Preventing the introduction and spread of invasive species is the most cost-effective defense against biological invasion. The second line of defense is eradication … When eradication is infeasible with existing technologies, then containment or long-term control of an invasive species population is the remaining management option. These programs often require substantial, if not indefinite, financial investments.

The present management strategy aimed at prevention and eradication only makes sense if the smallmouth bass population in the Glen Canyon Dam tailwater and in Grand Canyon remains small and localized. One proposal for post-2026 management of Lake Powell is to focus on prevention by eliminating the risk of entrainment of smallmouth bass by maintaining Lake Powell at a high target elevation. However, this management strategy will have to be re-evaluated in the coming decades. If smallmouth bass and other non-native species establish in Grand Canyon despite aggressive efforts at prevention and eradication, as might happen if Lake Powell elevations unavoidably plunge during an extended drought, then the best management approach in future decades might shift to containment or long-term management, as depicted in Figure 1 (see next page). Under such a scenario, maintenance of target elevations in Lake Powell and forgoing some hydropower production may not be warranted.

Scientific understanding and best management practices evolve with time. It is unwise to rigidly prescribe management strategies based on today's science and today's assessment of best management practices without allowing flexibility to adjust future annual releases and reservoir elevation targets to future ecosystem conditions, such as the status of invading species. For example, river and recreation managers live with non-native tamarisk (*Tamarix spp*.) that dominates floodplains throughout the Colorado River watershed, while strategies for widespread control using the tamarisk beetle (*Diohabda spp*.) continue to be explored. The history of tamarisk invasion that partly inspires the on-going effort to control smallmouth bass, but we are reminded that the efficacy of any management strategy depends on the status of the invasion.

No management actions are underway elsewhere in the Cataract Canyon/Lake Powell/Glen Canyon/Grand Canyon/Lake Mead region to manage or mitigate sedimentation at the upstream end of the reservoirs (Dehoff, 2022). Novel management strategies to address these sedimentation issues may be developed in the future,

19 Griffiths, R. E., Topping, D. J., and Unema, J. A. 2024. Changes in sand storage in the Colorado River in Grand Canyon National Park from July 2017 through June 2020: U. S. Geological Survey Open-File Report 2023-1093, 9 p.

20 U.S. Department of the Interior. 2021. U.S. Department of the Interior invasive species strategic plan, fiscal years 2021-2025. Washington D.C., 54 p.

while changing environmental and societal values may place greater emphasis on confronting these sedimentation issues.

Implementation of flexibility

Implementation of a flexible annual release policy is challenging. In March 2024, we described a strategy for accounting for the difference between actual water released in a year and a nominal negotiated agreement, and balancing those accounts every few years. We suggested that annual releases be adjusted to meet environmental conditions using that accounting scheme. We suggested that the decision about each year's annual release be made by the Secretary of the Interior or their designee.

Many people have suggested to us that this kind of flexibility introduces unacceptable uncertainty in managing reservoir storage and annual releases. An alternative approach to year-to-year flexibility in defining annual releases is to re-evaluate annual release prescriptions every few years, rather than every year. Such a re-evaluation of the values, goals, and management strategies associated with joint operations of Lake Powell and Lake Mead could consider environmental and societal resource values and be adaptable to the changing nature of those values and the changing status of reservoir storage, the need for hydropower, and environmental resources. The status of those resources might affect the environmental management strategies, such as suggested by the invasion curve (Fig. 1) that links management action with status of the invading population. Such an adaptive approach would provide flexibility in the deeply uncertain future.

In a subsequent paper, we specifically discuss the Glen Canyon Dam Adaptive Management Program and how it might better consider relict and artifact resources at the upstream end of Lake Powell as well as those traditionally considered in the Glen Canyon Dam tailwater and in Grand Canyon.

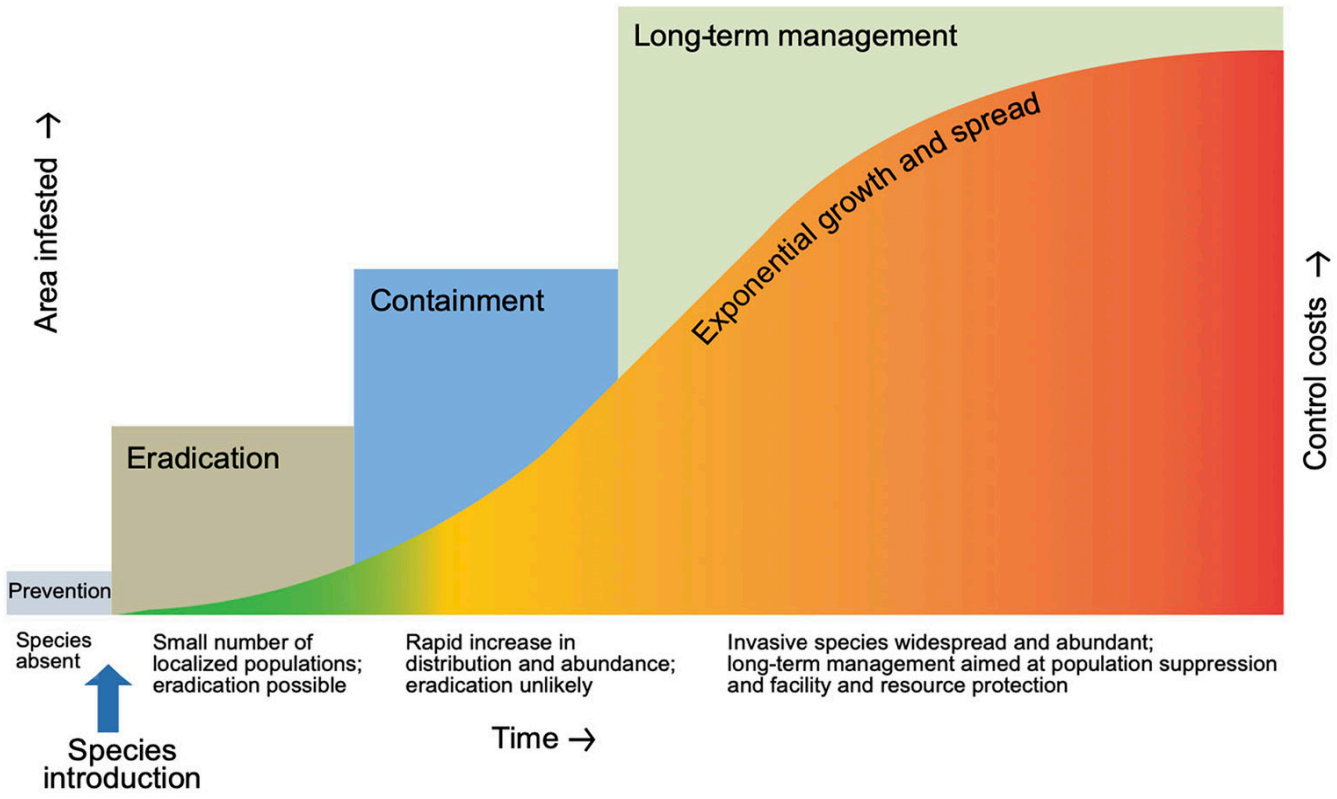

Figure 1. Conceptual diagram of the phases of the invasion curve linking population size and area invaded by an introduced species with appropriate management response (U.S. Department of the Interior, 2021[21]).

21 U.S. Department of the Interior, 2021, figure 2