6.0 Summary and Conclusions

Abstract. In Section 6, risks directly linked to biota transfers potentially associated with interbasin water transfers between Missouri River basin and Red River basin are summarized, and conclusions are developed. Absent priority, a simple list of conclusions includes but is necessarily not limited to:

(1) Interbasin transfers of untreated waters implemented via an open conveyance (e.g., canals) have a very high likelihood of establishing pathways to potentially promote biota transfers and subsequent biological invasions. While most of these invasions will fail in the absence of establishment of sustainable populations, such precursors to invasion will occur with near certainty. Although interbasin transfers of water via open conveyance has been dismissed as an option of choice, if interbasin water transfers occur via such a mechanisms, species invasions will occur and some species will establish populations in the receiving system despite any implementation practice adopted by Bureau of Reclamation or other government or nongovernment organization.

(2) Given life-history attributes typical of invasive species, biota likely to be successful at establishing sustainable populations in the Red River basin can be identified, although there is relatively great uncertainty associated with identifying which specific species may be involved in a successful invasion, given the stochasticity of the pioneering event.

(3) Historically, interbasin biota transfers have occurred independent of any designed engineering project linking the Missouri River basin and Red River basin; these biota transfers will continue to occur as a consequence of existing pathways (both natural and anthropogenic) and extreme events (e.g., floods) that are independent of any future human intervention. Management practices focused on prevention and control of biological invasions may minimize adverse effects associated with such transfers, and more optimistically, lead to the eradication of relatively long-established invasive species.

(4) Rosters of biota considered to be invasive are continually updated and additional species are being characterized as “emerging” or “reemerging” species of concern. Hence, poorly characterized or newly described invasive species must be anticipated and managed accordingly, e.g., analysis of risks must be updated periodically by resource managers.

(5) Interbasin transfers of water via a controlled and contained conveyance (e.g., piped from source to receiving system) will have less risk of biological invasions associated with their transfer, although the degree of risk reduction will depend upon the engineering design selected for the conveyance. For example, simply transferring water via pipeline from the Missouri River to a "point of engineering convenience" in the Red River basin will likely present risks similar to those associated with transfers completed via open conveyance, if a multiple-stage control system is absent from the transfer system's design.

(6) Interbasin transfers of treated water via a controlled and contained conveyance will present the lowest risks of biological invasion, and depending on the control system selected for implementation of the transfer, the likelihood of biological invasions being successful are much less than the likelihoods associated with biological invasions occurring via alternative pathways (natural or anthropogenic).

(7) Biological invasions associated with treated waters transferred through a controlled and contained conveyance would be more likely to be successful as a function of life-history attributes of the biota being transferred and not highly dependent on mode of transfer alone.

(8) The establishment of sustainable populations is less dependent on stochastic events resulting in an invasion than it is on the life-history attributes of the biota being transferred.

(9) Interbasin water transfers are also likely to indirectly influence biota transfers, biological invasions, their attendant outcomes, and potentially affect both source and receiving systems. Quantitative estimates of risks characteristic of indirect effects are precluded from derivation in the current report of technical findings. Analysis and estimation of risks associated with indirect pathways for invasion require greater specification of systems "at risk."

(10) Attributes of complex systems, and especially those characterized by engineering designs layered upon an existing landscape of natural and anthropogenic features, likely mean that the indirect or contributory role that multiple, interacting factors may play in the process of species invasion (e.g., augmented water flows may influence species invasions of riparian habitats previously subject to the vagaries of season water flows) will yield numerous low-probability events, which through time may be expressed as long as the interrelationships among constituent nodes remains fully characterized.

(11) For complex systems, the analysis of indirect effects becomes idiosyncratic and highly

scenario dependent. The focus of the present report has been on risks potentially associated with direct effects attendant to interbasin water diversions.

(12) If interbasin water transfer occurs with a multiple-stage control system built to implement diversion, there is still likely a future misassignment of linkage between water diversion and species invasions.

6.1 Introduction

John Wesley Powell, second director of the US Geological Survey, had observed in his classic "Report on the Lands of the Arid Region of the United States" (1878) that water was the arid region's [1] most precious resource but that very little of the remaining public land was suitable for conventional farming and that only a small fraction of the arid land was characterized by soils amenable to irrigation. In the "Report on the Lands of the Arid Region of the United States" (1878), Powell also suggested that water was more of a sociopolitical than a scientific problem. Powell's observations over 125 years ago still ring true, and this report continues USGS efforts to bring science to the decision-making process. Water demands continue to increase throughout the Great Plains and the western US (see NRC 1992; Rogers 1993). In the case of the northern Great Plains, the recognition of water needs and the anticipation of solutions to meet those needs has been, and continues to be, a well-traveled road, water needs approach infinity while finite water resources continue to shrink.

Water transfers within a watershed or between watersheds are an increasingly common component of regional water systems and are being considered in many locations for meeting growing water demands and for managing the impacts of drought (see, e.g., NRC 1992, Rogers 1993). Water transfers have long been a concern of water-resource managers, and historically, the topic has gained national and regional attention not unlike the issues associated with various visions of the Garrison Diversion. The balance of this closing section of the technical report will focus on summaries of risks of biota transfers, control systems and their role in reducing those risks, and the larger adaptive management context in which these technical findings are intended to be used.

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[1] During Powell's tenure as director of USGS, "arid region" was the US west of the 100^{th} meridian.

6.2 Control Systems and Reduction of Risks Associated with Interbasin Biota Transfers

If USGS were interpreting risks associated with biota transfers potentially linked to the proposed Garrison Diversion of the mid- to late-1970s, we too would have characterized risks as being "high," given the water control system proposed at that time to reduce risks of biota transfers associated with interbasin water diversions. Today, our analysis of alternative scenarios suggests that risks of biota transfers are high, if control systems are not sufficiently developed to offset the relatively high probability that biota transfers would occur if implemented via open conveyance (e.g., open canal) or contained conveyance serving to divert "raw" water (e.g., piped, but untreated water). A snapshot calculation of risk may appear relatively small to many observers, yet the range of risk estimates generated from the simulation study illustrates the uncertainty contributing to the decision-making process under which this, or any interbasin water diversion, operates. For interbasin water transfers completed in the absence of a multiple-stage control system (e.g., water pretreatment followed by stepwise water treatment using chloramination and ultrafiltration), risks of biota transfers approach "practically one" (that is, very likely to occur), given the number of trials that could inevitably occur through time. Seemingly an infinite number of trials would likely yield a "founding cohort" that breaches confining geographic barriers of exporting basin and subsequently establishes sustainable populations in the importing basin. In contrast, an interbasin water diversion completed using a multiple-stage water control system including pretreatment, chemical treatment, and ultrafiltration would be characterized as a low-risk venture where probabilities of biota transfers approached "practically zero," with species invasions or shifts in metapopulation dynamics strongly coupled with control system failure and stochastic processes that link independent steps within a flow of events that characterize the invasion process.

In order to reduce risks of biota transfers associated with interbasin water diversions, engineered systems designed to accomplish water transfers from Missouri River to Red River basins must consider our increasing, yet incomplete, understanding of technical issues related to invasion biology and the ecological perspectives that potentially influence water quality and quantity in Missouri River and Red River basins. Given the iterative character of the risk analysis and risk assessment process, the findings in this technical report reflect our initial foray into the interrelated issues of interbasin water diversions and the collateral effects potentially associated with biota transfers that occur consequent to that action. Three basic scenarios—transfer via open-water conveyance, transfer of untreated water via piped conveyance, and transfer of treated water via piped conveyance—were considered using multiple tools: narrative analysis, quantitative analysis, and simulation. As a point of reference, the technical analysis considered these interbasin transfers relative to a narrative analysis of a "within-basin" water supply alternative, and a narrative analysis of risks associated with mode of conveyance. If outcomes to companion efforts currently being develop by Reclamation (e.g., preparation of an environmental impact statement being prepared under NEPA) warrant, subsequent iterations of this process may be focused on engineering needs that require a targeted analysis of risk reduction measures to support control system design and specification.

6.2.1 Single-stage control systems and risk reduction. As indicated in Appendix 12, candidate technologies to support a single-stage control system vary from those widely used in current water supply systems (e.g., chlorination) to those whose application is relatively underdeveloped in domestic markets of the US (e.g., ozonation). The intent of the technical report was to afford stakeholders with sufficient background with these technologies to consider their role as risk-reduction measures and not to advocate one technology's use over another. Previous Reclamation efforts to address water needs in the northern Great Plains (e.g., Northwest Area Water Supply (NAWS) project) proposed a control system that was single-stage in construction but multiple-stage in practice (see contrasting views related to NAWS, e.g., http://design.eng.umanitoba.ca/resources/garrison_full.html and http://www.houstoneng.com/projects/naws/ last accessed December 6, 2004). As evidenced by water supply systems currently in operation throughout the US, control system designs may assume any of many configurations, which in part reflects various user needs (e.g., irrigation, rural and municipal use, industrial and high technology use) and their location relative to source water supply.

Regardless of technology of choice, no control system will be "risk free." Each of the water treatment technologies summarized in Appendix 12 have risks associated with their use as part of a control system; those risks cannot be avoided but can be minimized. And risks associated with single-stage control systems may be unacceptable for water resource managers, especially given the "competing risks." For example, chlorination has a long history of use in control systems as a water treatment technology with a performance history supporting its continued role in water disinfection (see Appendix 12). Yet the increasing awareness of risks associated with "disinfection by products" (DBPs, e.g., halomethanes) has required water users to revisit questions related to chlorination and competing risks related to health benefits associated with reduced occurrence of waterborne disease consequent to drinking water chlorination and increased risks associated with exposure to DBPs (e.g., increased cancer risks) in drinking water. Similar issues of competing risks exists for ozonation processes wherein formation of bromide becomes an issue owing to the collateral increase in cancer risks associated with exposure to bromide in drinking water (see, e.g., http://www.epa.gov/safewater/mcl.html last access December 6, 2004).

Review of Appendix 12 suggests that risks of biota transfer can be substantially diminished, if a control system is designed with that contingency in mind and providing performance criteria are specified against which a single-stage system can be designed and constructed. However, single-stage systems may not afford risk reduction sufficient to ensure skeptical stakeholders that biota transfers would likely not occur, e.g., disease agents such as *M. cerebralis*, the causative agent of whirling disease, and *C. parvum* are relatively resistant to single-stage chemical treatments such as chlorination. From a technical perspective, multiple-stage control systems afford another level of risk reduction that may be warranted, if costs associated with these systems are not prohibitive.

While multiple-stage control systems are generally associated with less risk than those associated with a single-stage control systems, the concept of "zero risk" remains unattained even with this level of design (see Schippers et al. 2004). As noted in Appendix 12 and captured in the simulation analysis in Section 3 and Section 4, multiple-stage control systems will never be characterized by zero risk given the inevitable changes in a system's reliability through time (see Appendix 4). However, risks relative to a control system and its product waters (e.g., increased health benefits associated with water disinfection and reduction in DBPs in treated waters) can be minimized with attendant uncertainties related to system performance. Potential system failures, however, contribute to our inability to attain a "perfect system" having zero risks. Technical findings summarized in this report do not recommend one control system over another with respect to specification or configuration, nor do these findings specify whether risks are acceptable and not acceptable. This initial iteration in the analysis of risks, however, suggests that risk associated with biota transfers could be reduced through implementation of water diversion via a multiple-stage control system that incorporates a conventional pretreatment (e.g., coagulation and flocculation), followed by chemical treatment (e.g., with chloramine) in series with ultrafilation. Rejection values vary across available pressure-driven membrane devices (e.g., microfiltration, ultrafiltration, and nanofiltration membranes), but ultrafiltration (or the equivalent technology yielding similar performance characteristics) would reduce risks associated with resistant life stages of disease agents such as viruses, bacteria, protozoa, and other microorganisms potentially occurring in source waters from the Missouri River.

6.2.2 Control systems for sufficient risk reduction to support interbasin water diversions. By incorporating economic concepts such as the "willingness-to-pay" and "willingness-to-accept" (see, e.g., Field 1996, 2000) into the analysis of risks and consequences potentially associated with interbasin biota transfers, outcomes of risk analysis can be placed in perspective. The economic principles may be applied to natural resource issues where monetary and nonmonetary costs are viewed within the context of "risk reduction" to allay stakeholder concerns associated with adverse effects that might occur as collateral damage to resource management policy (see Walters 1986). For example, risks of biota transfer may be reduced provided multiple-stage control systems are used to implement interbasin water transfers, but alternative options may be preferred by stakeholders, owing to other monetary or nonmonetary concerns. Similarly, within-basin alternatives may be associated with reduced risks, if water allocations among competing users can be reprioritized depending on resources most sensitive to reduced water availability, e.g., voluntary transfer of water rights between willing buyers and sellers. Water marketing may be used to meet "new" water demands, because the process encourages voluntary transfers rather than forced reallocations, e.g., water may be reallocated from lower-valued uses to higher-valued uses. As Garrison Diversion's history would suggest, interbasin water transfers often times are associated with significant economic, political, social, cultural and environmental concerns, so public interest criteria are needed to assess the viability of transfers. These criteria should distinguish between large and pervasive effects and smaller ephemeral impacts, although finding common ground among stakeholders presents a challenge to the resource manager. If resource valuation can be determined, then a marketing approach to dispute resolution may be gained in the process and risks of biota transfer can be fully integrated into resource management plans. As such, the prospects of biota transfers consequent to interbasin water diversions should be integrated into basinwide plans that likely exceeds the scope of any single resource management agency such as Bureau of Reclamation.

Our technical findings indicate risks of biota transfers, be those aquatic nuisance species or other biota of concern, e.g., aquatic vascular, and riparian and wetland vascular plants, identified by stakeholders during problem formulation, will vary as a function of control systems designed and constructed to realize water diversions. Biota transfers and species invasions are also subject to inevitable stochastic events. While "high-risk alternatives" such as open-canal conveyance and untreated water transfers may be infrequently considered options for implementing water transfers, these options provided alternative scenarios for evaluating risks. And not surprisingly, risks of biota transfers under these alternatives were high, and in some instances approached near certainty. Hence, those options, or engineering alternatives strikingly similar to those considered by IJC (1977), still present technically unacceptable risks for biota transfer. In contrast, risks of biota transfers associated with interbasin water diversion implemented with multiple-staged control systems in place present low, if not negligible, risks and do not appear as significant as those biota transfer risks forecasted over 25 years ago when control options considered by IJC (1977) were relatively limited. To a large extent, the observed "risk reduction" apparent between 1977 and 2004 stems from advances in water treatment control technologies, primarily the wider array of water treatment options currently available to reduce likelihoods that biota transfers occur, e.g., multiple control stages including traditional pretreatment, chemical treatment using chloramine, and ultrafiltration (see, e.g., Schippers et al. 2004).

6.3 Conclusions Regarding the Risks and Economic Consequences of Biota Transfers Potentially Associated with Interbasin Water Diversions

A simple summary of risks and conclusions suggested by technical findings of this report merely capture a snapshot of risks reflected by potential biota transfers directly associated with interbasin water transfers between Missouri River basin and Red River. Yet without priority, the dozen conclusions that follow may afford natural resource managers insights into biota transfer issues that presently challenge water management agencies and stakeholders focused on interbasin water transfers between Missouri River and Red River basins.

(1) Interbasin transfers of untreated waters implemented via an open conveyance (e.g., canals) have a very high likelihood of establishing pathways to potentially promote biota transfers and subsequent biological invasions. While most of these invasions will fail in the absence of establishment of sustainable populations, such precursors to invasion will occur with near certainty. Although interbasin transfers of water via open conveyance has been dismissed as an option of choice, if interbasin water transfers occur via such a mechanisms, species invasions will occur and some species will establish populations in the receiving system despite any "best management practice" adopted by Bureau of Reclamation or other government or nongovernment organization.

(2) Given life-history attributes typical of invasive species, biota likely to be successful at establishing sustainable populations in the Red River basin can be identified, although there is relatively great uncertainty associated with identifying which specific species may be involved in a successful invasion, given the stochasticity of the pioneering event.

(3) Historically, interbasin biota transfers have occurred independently of any designed engineering project linking the Missouri River basin and Red River basin; these biota transfers will continue to occur as a consequence of existing pathways (both natural and anthropogenic) and extreme events (e.g., floods) that are independent of any future human intervention. Management practices focused on prevention and control of biological invasions may minimize adverse effects associated with such transfers, and eradication of relatively long-established invasive species may attain limited success in the near future.

(4) Rosters of biota considered to be invasive are continually updated and additional species are being characterized as “emerging” or “reemerging” species of concern; hence, poorly characterized or newly described invasive species must be anticipated and managed accordingly.

(5) Interbasin transfers of water via a controlled and contained conveyance (e.g., piped from source to receiving system) will have less risk of biological invasions associated with their transfer, although the degree of risk reduction will depend upon the engineering design selected for the conveyance. For example, simply transferring water via pipeline from the Missouri River to a “point of engineering convenience” in the Red River basin will likely present risks similar to those associated with transfers completed via open conveyance, if a multiple-stage control system is absent from the transfer system’s design.

(6) Interbasin transfers of treated water via a controlled and contained conveyance will present the lowest risks of biological invasion, and depending on the control system selected for implementation of the transfer, the likelihood of biological invasions being successful are much less than the likelihoods associated with biological invasions occurring via alternative pathways (natural or anthropogenic).

(7) Biological invasions associated with treated waters transferred through a controlled and contained conveyance would be more likely to be successful as a function of life-history attributes of the biota being transferred and not highly dependent on mode of transfer alone.

(8) The establishment of sustainable populations is less dependent on stochastic events resulting in an invasion than it is on the life-history attributes of the biota being transferred.

(9) Interbasin water transfers are also likely to indirectly influence biota transfers, biological invasions, their attendant outcomes, and potentially affect both source and receiving systems. Quantitative estimates of risks characteristic of indirect effects are precluded from derivation in

the current report of technical findings, given the unspecified engineering designs proposed to mediate the transfer. Analysis and estimation of risks associated with indirect pathways for invasion require specification of systems with greater detail than currently available.

(10) Attributes of complex systems, and especially those characterized by engineering designs layered upon an existing landscape of natural and anthropogenic features, likely mean that the indirect or contributory role that multiple, interacting factors may play in the process of species invasion (e.g., augmented water flows may influence species invasions of riparian habitats previously subject to the vagaries of season water flows) will yield numerous low-probability events, which through time may be expressed as long as the interrelationships among constituent nodes remains fully characterized.

(11) For complex systems, the analysis of indirect effects becomes idiosyncratic and highly scenario dependent. The focus of the present report has been on risks potentially associated with direct effects attendant to interbasin water diversions.

(12) If interbasin water transfer occurs with a multiple-stage control system built to implement diversion, there is still likely a future mis-assignment of linkage between water diversion and species invasions.

Powell’s observations on water in the western US have in part been addressed through policy statements that guide “how water needs should be satisfied.” Yet at times these policy perspectives may conflict, e.g., precautionary measures vary with respect to implementation when encountering declarations with equally variable interpretation. Unfortunately, resolution of these conflicting views, or rather the interpretation of how these policies should be implemented, is not a technical problem even if technical solutions are sought. This technical report can only hope to bring an analytical perspective to the discussion of risks and consequences associated with biota transfers potentially occurring consequent to an interbasin water diversion. If the water diversion is realized, the risks of biota transfers range from “highly likely to occur” to “highly unlikely to occur,” depending on how the diversion is realized and with economic consequences matching these technical findings focused on risk. Technical findings summarized in this report are predicated on the assumption that water from the Missouri River is transferred to the Red River basin. Yet, until an overarching set of sociopolitical and socioeconomic questions—the same questions identified by Powell over 125 years ago—are answered, the issue of biota transfer will very likely be addressed in another report prepared by future technical analysts whose findings will be damned or praised, depending on the “eye of the beholder.”

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