Economic Assessment of Natural Resource Damages for Ground Water

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1. INTRODUCTION

Ground water is a natural resource commonly subject to state statutes and/or regulations that authorize recovery of natural resource damages (NRDs) caused by releases of hazardous chemicals. Injuries to ground water may also be compensable under natural resource damage provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[1] Natural Resource Damage Assessment (NRDA) is a process via which state and federal natural resource trustee agencies (Trustees), acting on behalf of the public, determine the amount that parties responsible for the releases (responsible parties, or RPs) must pay to compensate for injuries deriving from release of contaminants.[2]

Trustees and RPs use a variety of analytical methods to estimate the magnitude of NRDs. In this paper I discuss choosing among and applying alternative methods for estimating damages to ground water.[3] This effort is both warranted and timely. It is warranted by the wide disparity in approaches used and resulting estimates of NRDs. Such disparities arise both across sites with similar facts, and between the parties involved in assessing any given site; the range of damage estimates can be an order of magnitude or more. The result is an absence of predictability, and protracted negotiations or litigation can ensue. It is timely as concerns related to methyl tert-butyl ether (MTBE) and perflouroalkyl substances (PFAS) have increased the likelihood of an upsurge in the pursuit of ground water NRDs by Trustees.

NRDA involves matters of law, policy, science and economics. I contend that the wide disparities in damage estimates for the same or essentially similar events derives in relatively small part from differences in technical details of science or economics, and in

[1] The federal regulations for implementing natural resource damage assessment (NRDA) and restoration activities pursuant to CERCLA were promulgated by the U.S. Department of Interior (DOI) (43 CFR Part 11). Use of regulations during the natural resource damage assessment are optional unless used by "…Federal or State natural resource trustees in order to obtain the rebuttable presumption contained in section 107(f)(2)(C) of CERCLA" 43 C.F.R. §11.10. State statutes and guidance tend to mirror to a degree the federal CERCLA approaches, although some (e.g. in Vermont) are more similar to the approach under the Oil Pollution Act (15 C.F.R. pt 990).
[2] Sometimes the NRDA is a cooperative activity of both parties, the degree of cooperation varying across cases.
[3] Injuries are the bio-physical impact of contamination on resources and the services they provide; damages are the amounts of money owed by responsible parties to address these injuries.

relatively large part from differences in how the NRDA is conceptualized when relating the science to the economics and the economics to the law and policy. So, while interpreting ground water chemistry samples, or the exact statistical model used for economic data can be important, what matters more are high-level notions of how the overall analysis specifies the ways the affected ground water serves the public, the baseline from which impacts are measured, and the nature of the compensation that will be paid. Once these critical elements are aligned with site facts, and scientific methods constructed in a manner faithful to them, then operational implementation of the NRDA becomes one of details. I show in this paper that the primary sources of divergences in damage estimates are related to the overall architecture of the NRDA, not its detailed construction.

The broad architectural goal of a NRDA is to provide compensation that makes the public whole following a release of contamination that reduces the services provided by ground water from services that would have been provided absent the release. My perspective is that:

(i) law, regulations, and policy constrain *how* the making whole can be accomplished;
(ii) within these limits, the rational determination of *how much* compensation is needed falls within the purview of economics, and so the broad design of the assessment derives from the *choice of economic method* as it relates to the legal requirements; and
(iii) the details of science and economic analyses are then subservient to the chosen method, supplying the facts and computations that comport with the method and result in monetary damage estimates.

I focus here on the choice of economic methods, recognizing that these must reflect the constraints placed on the choice by law and regulations.[4] In particular, I stress how various methods and their implementation take into account the three primary drivers of NRDs: (i) the *baseline* relative to which damages are quantified; (ii) how ground water *services* are conceptualized when quantifying injuries; and (iii) the degree to which the computational methods used for *scaling* (or right sizing) damages match the way that the public will be compensated for the natural resource services lost due to the release(s) of contaminants at issue.

I do this primarily in the context of liability for NRDs under CERCLA, principles of which apply in the many states that mirror the basic CERCLA approach. I also address some other compensatory approaches that have been used in ground water cases. Under CERCLA, NRD monies collected must be spent on natural resource restoration, and so compensation is paid in-kind by augmenting ground water services in some manner. The other approaches I consider are distinguished in that monies collected may be spent in other ways, changing the form of compensation and hence how it should be scaled.

[4] This aligns with Brown (1993), who characterizes NRDA as a "joint product of law and economics," in which "Existing law, not to mention political considerations, constrains the design of economic procedures."

Even in CERCLA cases, the regulations need not be exactingly followed. Although I examine the CERCLA approach, my analytical perspective derives from basic principles and methods of economics for determining compensation, and so my analysis applies broadly to circumstances where that perspective is relevant. My take home message is that, to understand the differences in estimates of NRDs for ground water, and to see where difficulties may lie, one should first step back from details and examine how the estimate addresses (or intended to address) the three central issues of baseline, services, and scaling of damage awards.

The paper is organized as follows. Section 2 provides a high-level overview of the NRD assessment process and the basic issues involved. Section 3 delves more deeply into principles and methods for scaling of damages injuries as they may apply in ground water cases. Section 4 presents a series of "hypothetical case studies" that demonstrate the range of issues that have arisen. This section also generalizes the lessons learned from the case studies. Section 5 is a summary.

2. AN OVERVIEW OF THE ISSUES

Natural resource damages for ground water under CERCLA are determined in five steps:[5]

1. Injury Determination: Determining whether ground water has suffered *injury*, defined as measurable adverse effects caused by the releases of concern;
2. Injury Quantification: Measuring the amount of injury as the reduction in ground water services over time from what services would have been at baseline (absent the release, all else equal, including the effects of any remediation);
3. Restoration Options Analysis: Identifying appropriate restoration action(s) to address injuries;
4. Restoration Scaling: Right-sizing the restoration action(s) such that benefits provided ("credits" for service gains) balance (in present value terms) injuries ("debits" for service losses); and
5. Restoration Costing: Estimating the capital and operations and maintenance costs of implementing the chosen alternative(s); these costs constitute damages.[6]

In this section of the paper, I discuss Steps (1) through (4), identifying issues that often arise. I define and then highlight the effects of the three architectural drivers of damages: baseline, services, and restoration scaling.

Baseline: The injury determination must determine whether any resource impairments were caused by the release(s) at issue and not by something else. The quantified *amount* of injury therefore must include a counterfactual baseline analysis to specify exactly what services would have been if *only* the contaminant release had not occurred, with all the

[5] These are analytical steps; not steps in the NRDA process. In the CERCLA regulations, the first step is called Injury Determination the second is Injury Quantification, and three and four are Damage Determination. See Israel et al (2019) for an overview of these procedural steps in CERCLA cases.
[6] To the restoration damages would be added the Trustees' reasonable costs of undertaking the damage assessment as defined in the CRCLA regulations.

other influences on the system such as they were/will be. When specifying the baseline, it is typical to focus on the bio-physical attributes of the resource. It also is important to include the resource use implications of the regional water situation that provides context for the contamination event. This includes supplies and demands for water, as these depend on water infrastructure and management policies. The institutional framework for water management is often neglected in defining the baseline.

Services: These are the beneficial outcomes provided to other natural resources and/or people by natural resources.[7] There are three classes of services provided by ground water (Cantor et al., 1997):

- Extractive: benefits of using ground water for residential, agricultural, commercial, or other purposes;
- In-situ: benefits provided by the water while it is stored in the ground, such as preventing subsidence or intrusion of salt water into potable aquifers or non-use services that arise irrespective of current or anticipated use of water or the other resources it supports; and
- Ecological: benefits from supporting ecological functioning and/or human uses of resources when ground water discharges to sediments and surface waters.

One of my key points is that, while the *concept* of quantifying service changes from baseline is often stated in NRDAs for ground water, how services are conceptualized and measured in practice often falls significantly short of meeting this requirement. The basis for this assertion will be described in the case studies below.

Restoration: In a NRDA, compensation for injuries potentially can take place in many ways, and the *form* of compensation is important to estimating the right *amount* of it. Under federal statutes and many state policies, compensation takes the form of natural resource service benefits achieved via restoration of natural resources (henceforth "restoration"). Money damages then equal the cost of restoration projects. Two types of natural resources restoration may be performed: (i) *primary restoration*, which returns injured resources to baseline conditions or provides equivalent replacement resources, and (ii) *compensatory restoration*, also called *compensable value*, which serves as restitution for the *interim loss* of services from the time of the release until recovery to baseline conditions.[8] In cases not brought pursuant to the federal statutes, compensation may take forms other than restoration as defined above; in these cases NRDs is at times conceptualized as money damages, as in a tort claim, and NRDs recovered by the Trustees might revert to the general treasury or be earmarked for particular purposes in which case compensation comes in the form of public goods provided the public.[9]

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[7] This is the definition in the Oil Pollution Act NRDA regulations at 15 C.F.R. § 990.30.

[8] The terms primary and compensatory are used in OPA; in CERCLA, restoration usually means primary restoration, while compensation for interim loss of services is called compensable value. That interim loss is measured in concept as a *value* rather than as compensatory *restoration* has caused much error in NRDA, as will be discussed further below.

[9] Earmarking for use in restoring resources as the effect of the requirements of CERCLA, although perhaps with less preference for projects with a close nexus to injuries.

Based on this discussion, the high-level analytical issues in NRDA are: (i) identifying how, after accounting for the effects of the remedy, the contamination has caused the various services of ground water to be altered, relative to a baseline that reflects bio-physical, economic, and institutional factors; and (ii) identifying the type and amount of restitution that needs to be made to compensate for these service reductions by creating an equivalent service increase.

2.1 Injury Determination

In the context of ground water, injury determination is often accomplished by sampling ground water to see if concentrations of hazardous substances exceed regulatory standards and/or result in adverse changes in exposed biota. It also must be determined whether such effects can be tied to a release via a complete exposure pathway and are known to cause impairments in laboratory and field settings.[10] Injury determination identifies and documents the relationship between particular releases and specific impairments, generally defined as *measurable adverse changes* in natural resources.

Under the CERCLA regulations (43 CFR § 11.62), the injury determination criteria for ground water are based on the chemical quality of the water being such that (paraphrasing): (i) concentrations exceed water quality standards for potable water use *and* the ground water is either used or committed to that use before the release occurs,[11] or (ii) water concentrations cause injury to surface water or biological resources based on injury criteria for those resources.[12]

The CERCLA approach is consistent with distinguishing between ground water serving as a resource that provides extractive services, and ground water serving as a pathway to surface water that provides ecological services. Both fall under the definition of injury but have very different implications for injury determination as well as quantifying NRDs. This distinction is important; when ground water is a viewed as a pathway to surface environments, one can delink the ecological services affected from a need to restore *ground water* in order to address ecological service loss. A more directly-targeted restoration action, such as wetland restoration, might be preferred to address ecological service losses, if any exist. It is also noteworthy that the injury criteria recognize baseline *institutions* regarding extractive services; irrespective of the effect of a release on water chemistry, ground water is not injured if it is not potable or violates regulatory standards at baseline, or is not used as drinking water. It is also notable that there is no injury criterion that links to in-situ services, which might be taken to imply that in-situ services are ultimately tied to water use or impairments of ecological functioning.

Injury determination is partly technical and partly legal/procedural. Completing injury determination establishes: (i) that the observed injuries fall under the purview of the statutes, and (ii) a basic causal connection between the release and the injuries identified. Having completed the injury determination, NRDA practitioners will know the nature of

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[10] For more discussion, see Israel et al (2019), pages 88-95.

[11] The definition of a committed use (§ 62.14(h)) is a current use or a documented commitment (legal, administrative, or financial) to use the resource established before the release occurred.

[12] Air is also included, but it is hard to see this as a material consequence in most cases.

potential changes in the resource and the services it provides. This knowledge informs subsequent steps. Unfortunately, many injury determination analyses use measures that link to regulatory criteria, but that are not necessarily useful or informative in subsequent steps.[13]

2.2 Injury Quantification

Having identified that an injury occurred, the next task is to quantify the injury as a service loss, using some metric *that can then be used to compute damages*. The conceptual measure of injury is the net reduction in natural resource services from baseline. The use of services to quantify injury is explicit in the CERCLA regulations, which specify measurement as "…the reduction from the baseline condition in the quantity and quality of services…provided by the injured resource."[14]

The importance of the services concept for ground water is hard to over-emphasize, not only because it is how injury is quantified as stated in the federal regulations, but because it follows from more basic considerations. Since injury is a measurable adverse change in a resource, and services are beneficial outcomes provide by a resource then the quantum of adversity *must* be a reduction in service benefits; otherwise what exactly is the injury adverse to? Further, since a change must be from something, injuries must be measured as reductions in services absent the release, i.e. baseline services. Finally, compensation for interim losses (if required) is provided to the public, and public values for natural resources are defined in terms of services, broadly construed. The compensatory model in economics is *change in the resource → change in what resources do for people (services) → change in value*.[15] It is the change in services that is to be compensated via whatever form of restitution that is selected.

The changes being quantified compare two scenarios actual and baseline. In injury quantification, the actual scenario is the services *with* the release and remediation and the counterfactual baseline is services without these effects. The task of scaling damages is to add compensation to the actual scenario, in an amount such that the value of services in the two scenarios (now baseline and with the release, remediation and restoration) is the same.

2.3 Restoration Options

The federal statutes require NRDs collected to be spent on natural resource restoration. This section provides commentary on this dictate, as well as other possible forms of restitution for injuries. A high-level issue is the potential for a mismatch between the form of compensation assumed when scaling the amount of compensation needed and the way that compensation will actually be provided. An example is assuming in the scaling analysis that compensation is to be paid in money when it actually will be paid via services enhanced by restoring a natural resource. The former is only partially relevant to

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[13] The CERCLA regulations require that injury determination methods must also provide data of use in quantification (§11.64(a)(3)).
[14] At §11.70(a)(1).
[15] See, e.g. Adamowicz et al. (2008); Bergstrom et al. (2001); Bergstrom et al. 1996; and in the context of NRDA, Kopp and Smith (1993).

the latter. I will raise additional issues below about substitution during scaling of one good for another.

2.3.1 Natural Resource Restoration

As noted above, *primary* restoration speeds the return of resources and their services to baseline, while *compensatory* restoration compensates the public for interim loss of services between the time of the release and recovery to baseline. Obviously, there is a potential for both the remedy and primary restoration to overlap in providing primary restoration. Remedies are to be protective of human health and the environment, and when implemented, they may speed recovery of natural resources and their services to baseline. Consider a pump-and-treat system that shrinks a plume, and the treated, clean water is re-injected into the aquifer down-gradient of the plume. Here, the remedy also serves as primary restoration of the aquifer. This would not necessarily be the case if the remedy consisted of a containment system that isolated the plume but otherwise left it in place; the ground water may still contain residual contamination, which may or may not imply a compensable service loss.[16]

It certainly is incorrect to ignore the effects of the remedy on services when quantifying injury; this would be logically equivalent to quantifying interim loss while ignoring effects of primary restoration undertaken precisely to reduce interim loss. From an economic perspective, this raises the analytical issue of how to assess the reasonableness of expanding *either* the remedy or primary restoration *versus* compensating for residual service loss via compensatory restoration. The appropriate test compares benefits to costs, where the benefits of additional remedy or primary restoration is the implied reduction in the cost of compensatory restoration.[17]

The federal regulations provide various criteria for selecting projects.[18] The most meaningful here are a preference for (i) a close nexus between restoration and injury, defined in terms of types and qualities of services provided as well as geography, (ii) using well-proven technical approaches, and (iii) cost-effectiveness.

2.3.2 Other Forms of Compensation

Conceptually, compensation makes the public whole by restoring individuals' well-being to the level that would have existed but for the release. The restoration options analysis specifies *what* can be provided to the public to accomplish this goal. If one provides direct money compensation, as in a tort claim, then that money will be spent by its recipient on market goods or services; money here is a stand-in for what each person would purchase, which are real things and not money *per se*. If the analyst knew a person would buy a new boat to offset an impact to fishing quality, the scaling question is more fundamentally "how big a boat?" By giving people money, *they* choose how to

[16] Criteria under CERCLA for selection of a remedy would give some preference to the first remedy, but it is not absolute.

[17] Note that this is *not* equivalent to trading off the cost of remedies/primary restoration against the monetized economic value of having restored resources, as some analysts have suggested (e.g. Brown, 1993).

[18] See 43 C.F.R. 11 § 11.82(d).

spend it on the goods and services they deem valuable in offsetting the injury as they experience it. There is maximal substitution allowed (a boat or a golf vacation or new gutters), *within the class of market goods and services* and the context of household incomes and budgets. This is the theoretical stance used in most standard economic valuation methods for either marketed or non-market goods and services. As an aside, the device of money is beneficial as it allows the aggregation of value across people as well as across the disparate specific real goods on which it well be spent.

If the NRD monies collected revert to the general treasury, then the form of compensation is the bundle goods and services provided by government with the funds obtained. Assuming no earmarking of recoveries, one might ask about the marginal effect of some additional government funds. If earmarking occurs, it is the changes in the bundle of goods within the earmarked class.

2.3.3 Substitution and Restoration

That monies collected will be spent in particular ways constitutes a constraint on admissible substitution when determining how a general restoration of public well-being is to be achieved. In the realm of ecological effects, if the harm is to eagles and the restoration is building osprey nests, then that substitution (osprey for eagles) is imposed. A further degree of substitution would be imposed by compensating for the impacts to eagles by restoration of ground water that primarily provides drinking water services. Substitution may be limited by policy and a restoration project selection criterion that places a priority on projects that provide natural resource service uplift with a close nexus to services injured.

The set of admissible substitutions that derive from choosing a form of compensation has direct consequences for choice of economic method for scaling. For example, when the services lost and restored are the same, simplified service to service scaling is applicable, as will be described in detail in the next section. If the injured and restored resources are not substantially the same, then some *rate of trade* between them must be specified.[19] If the rate of trade is not well-specified this results in a biased estimate of the amount of compensation needed. In particular, if the amount of compensation is estimated assuming it is paid in a form that is not then adopted the result of this "bait and switch" is a significant source of potential bias.

Substitution also affects the estimated amount of compensation needed via cost-effectiveness. The degree of allowed substitution has two effects. If expansive substitution is allowed but one compensates by providing something that is a poor substitute for what was lost, this leads to more compensation being required, increasing damages. Countering this effect, more expansive substitution may allow a project that is cheaper to build, reducing damages. A more expansive restoration choice set always allows one to optimize the choice and select the cost-effective option that balances these potentially competing effects.

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[19] If the services provided are substantially the same, but produced in different ways, the rate of trade might be on the production side of service provision by altering inputs to the service production function. This would be a technical rate of substitution, rather than one on the demand side for different services.

2.4 Restoration Scaling

Having determined that an injury occurred and quantified the amount of it, as well as picked a form that compensation will take, the remaining technical issue is translating injury into money damages, i.e. valuing the injury. As just noted, under the CERCLA regulations and state statutes that mirror them, compensation *must* take the form of restoration. Valuation in the CERCLA regulations applies only to interim loss of services (compensable value). The regulations are slightly confusing here, and it is worthwhile sorting this out.[20]

2.4.1 Primary Restoration

The CERCLA regulations are written as if restoration of the resource to baseline conditions is a fixed goal. Once a *type* of restoration action is decided, the *amount* needed is determined by the goal of complete restoration, and all that is left is costing.

Of course, it is possible to specify a degree of primary restoration that achieves something less than full return of services to baseline levels. If this is predicated on a technical constraint because it is infeasible to get all the way back to baseline, then again, only costing of the amount and type of restoration is required, since the amount is fixed by the technical constraint. But suppose instead that the amount of primary restoration is a choice and compensatory restoration will also be undertaken, so that full compensation for service losses will be achieved regardless of the amount of primary restoration.

Then economic efficiency implies that the benefits and costs of the amount of primary restoration be compared, where the benefit of more primary restoration is the reduced cost of the compensatory restoration to be required. The optimum amount of primary restoration is achieved when the marginal cost of primary restoration equals the marginal reduction in compensatory project costs. Such a benefit-cost test would be applicable whenever one wanted to assess the relative merits of a primary versus a compensatory approach.

2.4.2 Compensatory Restoration

Compensable value is defined in the regulations as "…the amount of money required to compensate the public for the loss in services provided by the injured resources…" and "can include the economic value of lost services;" further, it is stated that such value "can be valued by consumer surplus…" (see footnote 20 for citation). This language seems to point towards *monetary damage* measurement, since consumer surplus is the amount of money, which if *directly* given to (or given by) an individual, will compensate him or her of a change in circumstances.[21] Further, the regulations mention contingent valuation surveys as one way to measure economic values associated with injuries; contingent valuation is a way to estimate consumer surplus, i.e. compensation in money. Nothing more is said about how such a monetary compensation measure might be used in *scaling* damages.

[20] The issues discussed in this section are presented in 43 C.F.R. §11.83(c)(1)-(3).
[21] On the concept of consumer surplus, see e.g. Freeman et. al (2014).

The CERCLA regulations go on to describe other specific methods that equate natural resource service gains from restoration to service losses due to injuries, in which case the monetary damages equal the cost of the restoration action(s) involved.[22] After mentioning these methods, the regulations summarize by noting that yet other unspecified methods can be used to measure compensable value that *either* estimate the public's consumer surplus *or* the cost of restoration that provides equivalent services to those injured (as long as these are reliable for their purpose). But why would a consumer surplus method, which *assumes* compensatory payments to the public in money in its construction, be appropriate when the law requires that "payments" be made in-kind via restoration?

In an attempt to clarify all of this, in standard economics, value is defined as the maximum amount of *goods, services, or money* an individual is willing to pay to obtain a specific good or service, or the minimum amount of *goods, services, or money* an individual is willing to accept to forgo a specific good or service.[23] I will somewhat loosely call this willingness to pay (WTP), with the same meaning as consumer surplus.[24] This definition of value admits latitude as to whether the resulting measurements are denominated in goods, services, or money.

Accordingly, valuation of injuries in NRDA can be tied to three basic approaches to restoration scaling as follows.

(i) Value-to-value scaling: Measure the value of the services lost due to injury denominated in some unit (either money, goods, or services) and measure the value of the services gained from restoration, denominated in the same unit. Restoration is scaled when these are equated. The units most often used are either money or services.

(ii) Service-to-service scaling: Equate services gained from restoration to the services lost due to injury. When certain assumptions hold, this approach can be justified as an approximation to value-to-value scaling. This approach includes resource equivalency analysis (REA), sometimes applied in ground water cases.

(iii) Value-to-cost scaling: Measure the monetary value of the services lost due to injury, and then spend this amount on restoration, bypassing the benefits of restoration.

Several sources of confusion about ground water NRDAs may be resolved with this view of scaling methods.

1. From a *measurement* standpoint, the concept of the money equivalent of damages is synonymous with the consumer surplus approach to compensable values in the CERCLA regulations. However, how these are then used fundamentally differ. With money damages, the plaintiff receives the money

[22] Methods mentioned include habitat equivalency analysis, resource equivalency analysis, conjoint analysis, and random utility models.
[23] This is substantially the same language as in the OPA NRDA regulations; see15 C.F.R. § 990.30.
[24] The usage here is informal, setting aside technical differences between Marshallian consumer surplus and Hicksian compensation measures; see e.g. Freeman et. al (2014).

to be spent as he or she sees fit, but in the latter the money must be spent on natural resource restoration, and consumer surplus is a method for scaling the amount of natural resource restoration to be implemented. This is value-to-cost scaling.

2. When the form of compensation actually will be the benefits of natural resource projects, value-to-cost scaling provides a biased estimate of restoration scale because it ignores restoration benefits. When one uses a WTP method to monetize the injury per the CERCLA regulations, to avoid the bias of value-to-cost scaling, one should also use a WTP method to monetize the benefits of restoration, and scale restoration to equate these two monetary values. This is value-to-value scaling.
3. When funds collected revert to the general treasury, with or without earmarking, it is *conceptually* reasonable to base scale on the benefits of the public goods to be provided with the additional budget. While this is logical, I have never seen this approach implemented in a NRDA.
4. As a matter of pure economic theory, there is nothing inherently inefficient or "non-economic" about compensation in-kind via restoration. The cost of restoration can serve as an alternative measure of value, conceptualized as WTP, if: (i) the restoration is a viable technical option for providing equivalent services to those lost; (ii) the chosen option is cost-effective relative to alternatives; and (iii) the cost of restoration is less than monetary valuation of injury and restoration benefits using a WTP approach.[25]
5. There may be practical impediments (cost and reliability of the methods) to measuring monetary losses as WTP that make the cost of restoration approach preferred. A particular concern is for hypothetical bias in contingent valuation surveys that often leads to an overestimation of true WTP.[26] Note that in value-to-value scaling, unreliability on the injury side may be counterbalanced by similar unreliability on the restoration side. I am *not* offering a "two wrongs make a right" rationale for applying unreliable WTP measurement methods, but as a practical matter, this is decidedly different than unreliability appearing only on the injury side of the scaling equation as with value-to-cost scaling.[27]
6. When restoration projects provide services similar to those injured (and some other assumptions apply), then service-to-service scaling provides a close approximation to value-to-value. This can bypass thorny problems of measuring service values, especially associated with non-use services, i.e. in-situ services thought to be arise irrespective of use of ground water for current

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[25] See, e.g. Freeman et al. (2014), pg 427. Note that number (iii) is the opposite of the "grossly disproportionate" ruling in the *Ohio* decision where restoration is preferred unless costs are much higher than the value created; see Israel et al (2017).

[26] Hypothetical bias arises when WTP as stated in a survey is different than an actual payment for the same change.

[27] In a recent case, during negotiations, the Trustees employed a value-to-cost analysis based on a contingent valuation approach that was extremely unresponsive to the scale of injury – assigning a very high value to both inconsequential and expansive amounts of bio-physical injury. When defendants noted that the same method implied that a restoration project of inconsequential scale would provide similarly high value, the WTP approach was abandoned in favor of a service-to-service analysis.

or future extraction, ecological support functions, or subsidence prevention. The question of when service-to-service methods are defensible will be addressed below.

2.5 Restoration Costing
In this step, scaled restoration (if it is used) is translated into dollar damages as the cost of the restoration projects(s). This includes the cost of designing the project, obtaining necessary permits, the engineering cost of the project, any contingencies included, and potentially monitoring of project success. The notions of contingencies to address uncertainties, monitoring of performance outcomes and potential corrective actions, re-openers, and the like are certainly important in practice. However, I will not address these issues here and simply assume the engineering cost of the scaled restoration is a straightforward step.

3. RESTORATION SCALING METHODS

The prior section set forth the relationship between the form compensation takes (i.e. how restitution is to be paid) and the scaling methods that correspond to these. In this section, I discuss each scaling method in more detail in the context of ground water.

The discussion will be aided (I hope) by a simple symbolic model of compensation scaling. It is assumed that the well-being achieved by individuals depends on the services provided by the resource suffering injury (I), service from resources to be restored (R), as well as money income (M) and the level of other services from public goods supplied by the government (G). The natural resource services are provided free of charge, the price of market goods is normalized to equal 1 (so money and expenditures on market goods are the same), and other government services have an average tax cost equal to τ per unit. Let the person's well-being be represented by a utility function $U(I, R, M, G)$.[28]

At baseline, resource services are at the levels I^o and R^o. I let Δx be a change in the variable x; for example ΔI is the quantified injury (service loss) from contamination. At baseline the person's utility is $U^o = U(I^o, R^o, M^o - \tau G^o, G^o)$, where the tax bill τG^o is deducted from income.

At a general conceptual level, having quantified injury as ΔI, the amount of utility lost (i.e. without any compensation) is

$$\Delta U = U^o - U(I^o - \Delta I, R^o, M^o - \tau G^o, G^o).$$

Compensation is achieved by providing enough of something else such that $\Delta U = 0$. Compensation can be paid in money (market goods) M, governmental goods G and/or

[28] It is not a small detail that this section is developed in a "timeless" manner so as not to be overly confusing. One can think of all these symbols as entire time paths of entities, discounted to a present date.

reductions in taxes τ (when NRD monies revert to the treasury), natural resource services from restoration projects R, or in principle, any combination of these.

Based on this idea, the "mother scaling equation" for all potential forms of compensation I will consider is defined to be

$$0 = \Delta U = U^o - U(I^o - \Delta I, R^o + \Delta R, M^o + \Delta M + \Delta\tau G^o, G^o + \Delta G; Z).$$

In its most general form, compensation is scaled via changes in the full utility function V. Once the economist has estimated the utility function, then he or she can compute changes in utility from the various elements of well-being (variables) and solve for a combination of compensatory changes that leave the person no worse off, given the injury. The economist computes the level of the utility function both at baseline and then with the release and a combination of restoration actions, and finds the set of actions that make ΔV zero.

It is a math fact that if the utility function U above is smooth (the function has no jumps or breaks or jagged parts; this assumption is likely innocuous), we may approximate ∇U by

$$\Delta U \approx -u(I^o)\Delta I + u(R^o)\Delta R + u(M^o)\Delta M + u(M^o)\Delta\tau G^o + u(G^o)\Delta G$$

where $u(x^o)$ is the marginal (incremental) utility of having a little more x when one already as x^o in hand.[29]

The marginal monetary value of a variable x (i.e, WTP for a small increment), is the marginal utility $u(x)$ divided by the marginal utility of income $u(M)$. We will define this as $v(x)$. For example, the value of injured services is $v(I) = u(I)/u(M)$, and similarly for the other variables. The approximation approach is useful in that one only needs to know the *baseline* values of the variables, which may be easier to determine than forecasting them over a whole range of potentially as-yet-unexperienced levels of the variables. This clearly requires effects to be small in some sense. That is, the approximation above is close when the changes are sufficiently small. [30]

3.1 Monetary Measures of Willingness-to-Pay

When the monetary equivalent of the injuries is sought, the measurement in concept is of WTP in money. In terms of ground water NRDAs for extractive services, this WTP would be based on the loss of extractive, ecological and in-situ services associated with a

[29] Here, the notation $v(x^o)$ is understood to mean the partial derivative of x evaluated at the baseline for *all* the variables; dividing by the marginal utility of income yields a baseline marginal value of a small change in x.

[30] Here small means that the change is small relative to the amount of curvature in the function U. If U is very curved in a term, then the change in that term needs to be very small, whereas if U is linear in a term, then the approximation is perfect no matter the size of the change.

change in ground water quantity or quality. Various measurement approaches are available.[31]

Turning to the mother equation, set ΔR, $\Delta\tau$ and ΔG all to zero. Then $\Delta U = 0$ exactly when $\Delta M = \Delta I \times v(I^o)$. *The amount of money needed in compensation is the service loss due to injury times the monetized value of injuries, or the marginal WTP for services times at baseline times the injury*. This latter term is the marginal utility of services divided by the marginal utility of income. This term is the "consumer surplus" of the CERCLA regulations in this model.

Note that ΔM is an amount of money which, by construction, is directly given to the person harmed. So, how might one determine the monetized value of the injury?

Regarding extractive services, this is clearly a value in use. Residential use is typically included in NRDA as a public loss; extraction for agricultural and commercial uses are subtler. Claims for lost accounting profits by firms are not compensable as public NRDs.[32] My focus here on the extractive services is on the residential demands for water.

When a resource is directly used by people, a class of methods called revealed preference (RP) are available. With RP methods, we have the following logical pathway of measurement: *change in the resource from baseline → individuals' experienced change in services → changes in behavior → infer value of change.* Since behavior changes reflect trade-offs being made by individuals, they can be used to reveal value. For example, suppose ground water contamination leads to a reduced supply of water and so a higher price of water delivered to households. Then less water will be purchased and this behavioral response reveals a trade between water quantity and money, i.e. a WTP for water. Behavioral changes depend on availability and cost of substitutes. The first three steps in the pathway are data to be collected; the last is the analysis by the economist.

Regarding extractive services, methods include looking at purchases of substitute water, effects on housing purchase decisions, and via water markets, either with actual trades or as dictated by water delivery institutions (e.g. pricing by water purveyors).

Regarding ecological services, we may also have a use of ground water by people, but now the effects are indirect. Suppose contaminated ground water is discharged to surface water and this discharge causes a fish consumption advisory that leads anglers to fish less often and/or in other locations. This is revealing a trade between resource quality and money spent on fishing, i.e. a WTP for better fishing. A reduction in surface water flows may be caused by remedial actions, impairing habitat for fish. Again, we can trace this through to the choice behavior of anglers or other users, revealing value lost.

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[31] See, e.g. Freeman et al. (2014) for more details.

[32] On the relationship between public and private claims in damage assessment, see Jones et. al (1996); the analysis of resource rent is in terms of a fishery, but similar issues arise for ground water. A full treatment is beyond our scope here.

The second class of methods is called stated preference (SP). Here, the behavior change is not in response to a real-world situation, but one elicited via a survey administered to the public. After posing a scenario describing contamination in some fashion, the survey respondent is asked how he or she would respond to this, by a hypothetical behavior. Thus, the survey seeks to set up a contingent market where a response to the behavioral question ("Would you vote yes or no to the program if if cost your household $_"), if it were real, would embody a trade-off that can reveal value. The behavior stated in answers to RP surveys can be thought of as a behavioral *intentions,* e.g. how, at the time of the survey, the person would vote in a referendum if it were real. The logic pathway of SP measurement is: *describe a change in the resource → describe how this changes services → elicit intended change in behavior → infer value of change.* In this sequence, all of the steps are constructed by the economist, while the respondent provides the behavioral intention by answering the questions written by the economist / survey designer.

One example of an SP analysis might be directed to an intended change in use behavior, such as how much less often the respondent would go fishing if there was a consumption advisory.[33] Another example would be whether the respondent would vote yes or no to a program that would fix a ground water contamination problem described in the survey at some hypothetical cost to the household. This is an example of a contingent valuation (CV) survey. As an example, Bergstrom et. al (2001) describe studies of nitrates in Maine and Georgia that posit in a CV survey a program to keep future levels of nitrates in ground water below federal standards. The program would be funded by a "special tax" levied over 10 years. The different survey respondents are given different levels of the annual tax to their household, varying from $25 to $500 over the sample. After learning some facts about the nitrates in ground water and potential health and other effects, the respondent is asked whether he or she would vote yes or no to the proposed program at the stated tax cost. This hypothetical referendum approach is commonly used in CV studies. These data can then be used to statistically estimate the average WTP for changes in ground water quality.

Another SP variant, called a choice experiment, uses hypothetical options for purchase presented in the survey in terms of a list of attributes, one of which may be price. The survey respondent makes a choice of one option (which may be no purchase) thereby revealing a willingness-to-trade cost for the attribute bundle in the preferred choice. If one attribute pertains to ground water quality or quantity, then changes in that attribute can be valued in the analysis of the hypothetical choice data.

The RP methods can be used to estimate values for changes associated with direct or indirect use of ground water. The SP studies can be used to address these use values, as well as so-called non-use values, hypothesized to exist irrespective of an actual behavioral trail associated with changes in use. Thus, if there were a value (WTP) associated with the non-use, in-situ service "having clean water in the ground" (or in

[33] This is called contingent behavior to distinguish it from asking a contingent value (WTP) question.

surface water and associated ecological effects) and these were held irrespective of use, then such a non-use value could only be estimated by SP methods. I will comment more on this in the Section 4 of the paper, using examples.

The economic literature that developed these methods is focused on values to be applied in benefit-cost analysis (BCA). In a BCA, the cost of a pubic project, program, or policy is defined as an opportunity cost – the benefits of the goods that could be produced if the resources devoted to the project were instead put to their next best - but typically unspecified - alternative use. This becomes the usual dollar cost if (i) the project is small and has only a marginal impact on the overall economy and (ii) market prices provide a WTP value for a small change in goods.[34] To be commensurate with costs, *benefits must then also be denominated in dollars*. This is how non-NRD economists naturally think about things.[35] The monetary valuation methods, either RP or SP, assume in their construction that the money involved is paid directly by (or to) people and so in principle relate to private household budgets.

Further, BCA relates only to *hypothetical* compensation. The approach says: if the benefits of a project exceed its costs, it is possible for those that gain from the project to pay compensation to those who lose as a result of the project and have something left over. Thus, it is possible *in principle* for society as a whole to be better off, since the losers, having been (hypothetically) compensated are no worse off, and the winners are strictly better off even having paid the (hypothetical) compensation.

NRDA is *not* the same as BCA. First, the whole idea is for compensation to *actually* be paid. Second, as seen in Section 2.4 Point (7), replacement cost can serve as a measure of value in particular circumstances – ones that happen to apply in the case of compensation via restoration. In this case, what is provided in compensation is not money to be used as the individual sees fit, but something specific and concrete. Thus, rather than comparing a concrete project output to the benefit of an abstract alternative benefit associated with opportunity cost (as is done in BCA), NRDA seeks an equivalency between a concrete loss of injured resource services and a specific gain in restored / replacement resource services. This allows methods other than those developed for BCA to be reliably applied.[36] The role of a WTP here is to judge whether providing the restored services is "worth it" rather than to determine the amount (scale) of restoration.

3.2 Scaling Methods when Monies Revert to the General Treasury

If monies collected as NRDs go to the government, the BCA style WTP methods to estimate ΔM as just discussed are not directly applicable. Instead, the benefits conferred

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[34] This means competitive prices – if markets are distorted, then "shadow prices' that mimic competitive conditions replace market prices.

[35] In a widely-cited text on valuing environmental goods that is 445 pages long (Freeman et al; 2014) exactly 2 short paragraphs are devoted to replacement costs (i.e. the measure of damages in CERCLA) and service-to-service methods (Resource Equivalency Analysis), widely used in NRDA, is not mentioned at all.

[36] By which I mean reliable in principle, assuming accurate implementation.

to the public by the NRDs collected accrue in the form of more public goods, tax relief, or a combination of these. Returning to the mother equation for scaling, set ΔR and ΔM to zero. Solving for the change in government services provides

$$\Delta G \times v(G^o) + \Delta\tau = \Delta I \times v(I^o).$$

In words, the monetized value of the change in other public goods (whatever these may be and as constrained by possible earmarking) plus any reductions in taxes, is set equal to the monetary value of the injury.[37] The first term is the marginal WTP at baseline for the extra public goods provided.

One approach is to assume that the overall budget and its fractional allocation to various public expenditures do not change, in which case $\Delta G = 0$. In this case, the recovery of NRD funds acts as a reduction in taxes. As a subtlety not reflected in the above symbolically, taxes are levied on goods and/or labor, distorting prices away from their market values. The public benefit of a tax reduction is then measured in a more nuanced way as a reduction in the economic "excess burden" imposed by a tax system that distorts economic outcomes.[38]

Another approach would set $\Delta\tau = 0$ and posit increases in specific public goods provided (education, health, infrastructure, etc.), perhaps related to earmarking of funds recovered from RPs. One would then measure peoples' willingness to pay to obtain specific changes in these public goods in compensation for a loss of ground water services. This is another "concrete this for a concrete that" valuation. The cost-minimizing bundle of public goods that provide equivalent compensation for the reduction in ground water services caused by the release would then provide a correct scaling.

These differ from those typically used in environmental cases. Note that, relative to giving people money directly, the economic methods derive from a different restriction on the restoration options and the ability to substitute one thing (e.g. reduce class size in schools) for another (a reduction in ground water services) when determining restoration scale and damages.

3.3 Compensation via Natural Resource Restoration

The final set of scaling approaches derive from a restriction that compensation must be in the form of the benefits of natural resource restoration projects, as for example under CERCLA and similar state programs. These approaches focus on providing benefits of restoration equivalent to the interim loss of services caused by the release at issue.

[37] Note that when ΔG is provided, taxes don't go up, as this is paid for by the RP. The tax change is a reduction in taxes, again provided as part of compensation, funded by the RP. Note too that I am talking about distorting taxes, not a corrective tax levied on an externality, such as an air pollutant.

[38] How to levy taxes to minimize negative effects of distortions while raising a given aggregate amount is a classic problem in the topic of optimal taxation; see e.g. Atkinson and Stiglitz (1980). It is not at all simple to determine.

3.3.1 Value-to-Value Scaling

Setting ΔM, $\Delta\tau$ and ΔG to zero, the scaled amount of restoration ΔR, satisfies $V(I^o, R^o; M) = V(I^o - \Delta I, R^o + \Delta R, M)$. Damages equal $C\Delta R$, where C is the unit cost of restoration.[39]

Using the approximation, scaling requires

$$\Delta R = \Delta I \times \{v(I^o)/v(R^o)\},$$

i.e. the monetized value of restoration is set equal to the monetized value of the injury. The ratio term in brackets is the rate of trade between the injured and restored resources.

3.3.2 Service-to-Service Scaling

A second approach to valuing restoration is called service-to-service scaling. Here, losses and gains in services are equated, but no values are involved; rather, the service losses measured in the injury quantification are equated to the service gains from restoration. In the context of either ground water as a resource or as a pathway to ecological resources, REA has been used frequently in ground water cases. The use of REA in ground water cases is controversial, a topic I will discuss in detail below.

The service-to-service approach can be derived from the symbolic analysis above. If the injured and restored services are of the same type and quality, so there is perfect substitution between restored and injured services, then value terms in brackets in the previous section are equal, and the rate of trade is 1. In this case, the service-to-service scaling equation

$$\Delta R = \Delta I^o$$

is fully legitimate.[40] Thus, I have derived a set of conditions under which service-to-service scaling is consistent with the general economic theory of compensation.

The use of service-to-service scaling methods as implemented via REA, has been discussed in the literature (e.g. Zafonte and Hampton, 2007)) and presented in cases (see Snyder and Desvousges, 2013) as a viable approach for scaling compensatory restoration. The REA approach uses a volume or flow as a metric to quantify injuries, with an equivalent volume or flow being provided by the restoration project(s). Thus, in terms of the scaling equations above, the services provided are assumed to be directly proportional to the amount of water, so the latter measures the former.

Only if several stringent assumptions hold can scaling be done in terms of a single physical measure such as a volume of water as in a simple REA.[41] REA is defensible only if (i) all ground water services move in direct proportion to the chosen metric, (ii)

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[39] See Parsons and Kang, (2010) for an example. One might also do this in two steps; do a BCA-style value study for injury and another for restoration; scaled restoration would equate the two results.

[40] As long as the scaling equation in marginal values closely approximates the "mother equation."

[41] See, e.g. Jones and Pease (1997); Dunford et al. (2004).

the effects are "small" in the sense that approximation above is "close"; (iii) the services provided by the restoration project are of the same type and quality as those injured and also move in proportion to the injury metric; and (iv), in a model with a time dimension the marginal values of ground water services are not changing over time, which effectively means the baseline is approximately constant.

3.3.3 Value to Cost Scaling

I have already stated that using monetary values to determine the scale of restoration (i.e. value-to-cost scaling) is biased by virtue of failing to include restoration benefits. This bias can be seen by a rearrangement of the value-to-value scaling equation, and bringing in project costs so the result is stated in terms of damages, equal to $C\Delta R$. The damages under value-to-value scaling equal $C\Delta R^{VTV}$ and under value-to-cost scaling equal ΔM, the scaled monetary compensation using the WTP for injury (since $\Delta R^{VTC} = \Delta M/C$.) Defining the "benefit-cost ratio" for restoration as

$$BCR = \Delta R v(R^o)/C$$

One can derive

$$C\Delta R^{VTV} = \Delta M/BCR.$$

Thus, only if the BCR happens to equal 1 is value-to-value scaling unbiased. With careful restoration project selection, as occurs in almost all NRDA cases, it would be expected that the BCR is greater than 1, and that value-to-cost scaling leads to an upward estimate in damages estimates. Despite this bias and revision of the CERCLA NRDA regulations to allow restoration costs to measure compensable values, some state Trustees continue the practice of valuing service losses in monetary terms using BCA-style methods, and then equating this to damages and hence restoration expenditures. It is simply wrong in principle, setting aside the additional difficulties that arise in the measurement of values.[42]

This same result holds in slightly different form whenever the monetary valuation of the injury ΔM is computed and then, instead of giving this to people (as assumed when it is computed), this is used to scale restoration *provided in another form*. This is the basic mis-match that can occur. It of course would also hold for any other combination of measurements such that compensation is scaled assuming one form of compensation, and then compensation is actually provided another way.

3.4 Services, Values, and Defensible Scaling

In any of the above scaling approaches, the accurate translation from the fact of contamination caused by a release to an aquifer (injury determination), into a loss of services of that aquifer in the (injury quantification) is a crucial step. Scaling is the

[42] Such an approach could only be rationalized by a high cost of information needed to implement viable alternatives. See Byrd and Dunford (2017) for a discussion in terms of impacts to recreation from an oil spill.

process of equating the value of the loss of services of an aquifer caused by contamination, to the incremental value of service enhancement provided by restoration. These values all depend of course on the form of compensation. This is the critical step of adapting how restoration is scaled to how it is paid. The measurement of service gains on the credit side of scaling are as important as service loss measurement on the debit side. A substantial mismatch here is a fatal flaw in the analysis.

As has been demonstrated in the preceding text, all of the appropriate approaches to scaling employ economic methods at their root, requiring careful consideration of changes in ground water services provided, to whom and when, how those services changes are mediated by water management institutions that service provision at baseline, and the relative economic values that would be attached to these services. Such scaling recognizes all the behavioral reactions made by individuals (i.e. by regulators, companies, water purveyors, and citizens) to mitigate possible effects by undertaking remediation and providing or availing oneself of substitute resources. Such scaling also recognizes the relevant baseline, including both effects of the remedy, and institutional overlays to the regional supply and demand for ground water services. These are all part of the utility function, definitions of variables, and marginal values in the analyses just presented.

4. SERVICES, BASELINE, AND RESTORATION SCALING

In general, the results of the previous section pertain to extractive, *in-situ*, and ecological services provided by ground water. I will now apply the framework developed above to specific aspects of determining damages for injuries to ground water. Rather than discuss these issues in the abstract, I use six examples that highlight various issues that arise in practice, and the conceptual difficulties alternative approaches may entail. These are not true case studies but vignettes drawn from actual cases that I have worked on or know about. All demonstrate the foundational roles of a proper definition of baseline, a careful accounting process for service changes in scaling, and the form of restoration in the analysis.

4.1 Discussion of Case Scenarios

Case Scenario 1

> *At baseline, an inland aquifer supplies public drinking water via an extraction well, with the pumping rate limited by regulations to the sustainable yield of the aquifer.*[43] *After pumping, the water is delivered to households and household waste water is sent to a water treatment plant where it is treated before discharge to a river. There is no discharge of contamination to surface water. After discovery of contamination in the aquifer, wellhead treatment is installed at the affected supply well. In the short period before the treatment is installed and the affected well is brought back on line, the town uses, at minimal added cost, backup supply wells in unaffected portions of the aquifer. Once the treatment*

[43] The amount that can be pumped and not draw down the aquifer, and so equal to the amount of recharge.

> *system is on-line, the water is delivered to the same households, waste water is delivered to the same water treatment plant, and discharged to the same river. It is estimated that the aquifer will be fully restored via treatment in 20 years. The Trustees conduct a REA on the amount of recharge within the plume area and seek restoration that involves purchase of land providing equivalent recharge to regional drinking water aquifers and protection of the land from development by making it a park.*

It is a challenge to identify any extractive, ecological, or subsidence prevention service losses in this scenario. However, the ground water REA, operationalized using recharge rates, indicates that compensatory restoration is needed. This could only be justified based on a pure non-use theory of injury. The proposed restoration does more than provide non-use ground water services. Further, the park provides recreation benefits that were not injured. Even if there had been 100% loss of all ground water services due to the contamination (which there was not), there needs to be a recognition in the scaling that the restoration is providing more services than those lost. Thus, restored services are not of like quality and value to the services lost and the assumptions of REA do not hold.

Averting Behavior

One possible service loss in the above scenario derives from a hypothesis (that would need to be tested) that some individuals prefer to use water that has not been through a treatment process for the contaminants and so avoid the publically-supplied water post-contamination and use bottled water instead. Towns frequently blend water from multiple sources to meet drinking water standards, and the courts have sometimes used such standards to indicate when any injury exists. Thus, there may be no compensable damages even under the hypothesized behavior change. But even if there were, this type of service loss and induced behavioral change can be evaluated using established RP economic WTP methods for assessing losses based on the averting behavior of buying bottled water, the cost of which provides a bound for the losses (see, e.g. Bockstael and McConnell, 2007, and Abdalla et al., 1992). But the amount of switching to bottled water (if it happens at all) and the associated cost of this will not scale simply to a volume or flow of contaminated water and so a REA would not be appropriate.

This of course begs the question of the form of restoration that is most appropriate. As the injury is denominated in dollars, any of the types of restoration can be used, as long as the appropriate BCR is applied once the restoration is chosen.

The general insight applies: particular sources of service loss are best addressed using targeted economic analyses and not broad-brush tools.

Imperfect Substitutes

Had the water supply prior to contamination been private rather than public wells, with the response entailing a switch to a public supply, the question might arise as to whether the replacement water is a perfect substitute for private well water. There are some differences in attributes that might mean the replacement is considered to be either better (enhanced reliability, fluoridation) or worse (a preference for independence, non-fluoridation). The degree of substitution of replacement water with original water is an empirical question. The appropriate scaling needs to incorporate this via the rate of trade defined in the previous section.

Case Scenario 2

> *The case involves an aquifer adjacent to a river that is a source of contamination in the sediments and water in the river, which is alleged to harm fish, birds, and recreational use of the river. The aquifer is not used for drinking water, and no other service losses are asserted. The Trustees conduct a REA for ground water and assert 100% loss of aquifer services. The restoration is remediating a nearby orphan plume in a deeper water supply aquifer to drinking water standards.*

While there is a potential loss of ecological services, the use of a REA for ground water and restoration of extractive services in a nearby aquifer represent a mismatch to actual service loss. The restoration of the full services of the orphan plume provides more than just ecological services. A more direct and potentially useful way to approach the NRDA is to examine the ecological losses, conduct an injury analysis for them and determine how best to restore them. The answer might be along the lines of enhancing a wetland (to restore sediment and water services to fish and birds) and building a boat launch (to restore for lost recreational use). This would be a service-to-service approach, but applied to restoration that actually provides similar services as those lost. The error in the scenario is to leave out the rate of trade between restored and injured resources.

Case Scenario 3

> *The case involves an aquifer in a water-short area that relies heavily on ground water. Wells are restricted to pumping no more than maximum sustainable yield. A portion of an aquifer is rendered non-potable by contamination, although due to land use restrictions on-site (the site is a military facility), no supply wells exist in this portion of the aquifer. The sustained yield of the aquifer is used for water supply downgradient of the site. The remedial action is to fully contain the aquifer on-site and to pump, treat, and re-charge the aquifer with treated water at the down-gradient edge of the property ground water.*
>
> *The Trustees assert a loss of extractive water services under the property, as well as in a buffer area on either side of it that extends to the edge of a cone of depression that would be created by a typical extraction well.[44] A REA is used to scale the remediation of a nearby orphan plume that currently renders that portion of the aquifer unavailable for consumption.*

The basic difficulty with the Trustee method is a mismatch between the asserted service loss and the restoration. There was in fact no loss of extractive *water* services (sustained yield) due to the contamination because the remedy results in the delivery of water meeting drinking water standards downgradient. Further, there is no loss of *water* in the cone of depression; a well needs to be placed that far from the aquifer (i.e. at the edge of

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[44] When a well extracts water, it typically causes a reduction in height of the water table; the reduction is greatest at the well, and decreases to zero at some distance from the well. The area with a reduction is called the cone of depression and represents the area of the aquifer from which the well draws water.

the buffer area) precisely so that the water between the contamination and that location *can* be accessed. The Trustees' injury analysis instead posits a lost service that might be called locations to access water by placing a well. There was no loss of this service at all on-site, due to the restrictions on land use existing at baseline. There was a loss of this well placement service in the buffer area, but this is not related in any way to the restoration, which provides additional water. It is the water that is in short supply in the region – not places to site wells.

<u>*Case Scenario 4*</u>

> *The site is adjacent to a major river in the northeast. Due to heavy pumping for residential water use in a town downgradient of the site, the natural ground water flow toward the river has been reversed and water is drawn toward the town's extraction wells. There is a sustained-yield limit placed on extraction imposed by water management authorities to avoid the disruption of base flows to local streams in the water-poor area downgradient. The remedy on site is a pump-and treat system that captures flow and discharges the treated water to the river, which then flows to the ocean.*

Here, the contaminated aquifer is highly valued for its ecological services and the management restrictions at baseline reflect this value. Thus, much of the water in the aquifer has a highest and best use of remaining in the aquifer (i.e. the highest and best use reflects *in-situ* services), with extractive services limited to sustained yield at the current head height for the aquifer. There is a loss of sustained yield downgradient due to the interception of this amount of water and discharging it to the river, where water is not in short supply, so there is no offsetting increase in services there. Thus, there is a loss of extractive services; if the pump-and-treat system were not operating the town could increase its pumping rate.

There are two possible measures of this loss. The monetary damages ΔM would be measured as the WTP of the people in the towns' service area to have an increase in water. A demand curve for residential water use could be estimated and the WTP for water estimated as the lost consumer surplus. As discussed above, if there is a requirement that damage monies be spent on restoration, or if they revert to the general treasury, this WTP-based measure is not conceptually appropriate. Alternatively, a restoration project could augment water supply to replace the lost sustained yield from the pump-and-treat. This could be a gray water use project that diverts gray water to irrigation (there is a nearby golf course that irrigates with fresh aquifer water) thereby freeing-up more fresh water to meet residential demand, or an increase in delivery from alternative surface water source (such as the river). The cost of such a project would constitute a restoration-based measure of damages.

<u>*Case Scenario 5*</u>

> *The site is in a dry area in the west, where there is heavy use of ground water as well as a surface water supply from a major river. A city's water supply is all from ground water, but pumping is limited by several institutional controls: (i) to prevent the high costs of subsidence, heads cannot be drawn below a 200 foot*

> *limit and (ii) due to downstream requirements and in-stream ecological values, ground water pumping is limited by an interstate compact. The allowed amount of water can be accessed in any location, but must be limited in the aggregate. The plume is being remediated. The Trustees assert a large loss of water to be used for extraction and delivery to the city, down to 2000 ft depth under the plume area plus a buffer area defined by the edge of the cone of depression. They propose a restoration of building a large surface reservoir to replace the aquifer, in part to serve the city's needs in case of a future drought, at a cost of several billion dollars.*

Due to the institutional controls on drawdown operating at baseline, the water in the aquifer from 200 ft of depth to 2,000 ft of depth has a highest and best use of remaining in-situ and for this portion of the water, extractive services are not lost. As argued for Case Scenario 2, the "buffer area" argument does not imply a loss of water, but rather a loss of place to site a well. But this is neither the subject of the claim for lost extractive services, nor in short supply in the region due to the policy regime of being able to access water at any location so long as downstream obligations are met. Regarding the remainder of the aquifer in the top 200 ft under the plume, the city had changed the place of diversion for this well, and this had been paid for by the RP; for this reason, pumping data showed no decline in aggregate delivery after the contamination was discovered. Further, in case of potential future drought, the water in the usable portion of the aquifer could be accessed by using wellhead treatment and blending to meet drinking water demands. Further, the surface reservoir is impractical in this arid region and likely could never be permitted; thus, it seems speculative in nature rather than a viable restoration option.

<u>Case Scenario 6</u>

> *The site is a large city in the upper Midwest. The city relies in large part on ground water and in smaller part on surface water diverted from the river through a water treatment plant, the size of which limits delivery capacity to only a small fraction of average river flow. There are no down-river delivery requirements. The city currently pumps from the aquifer substantially more than recharge from rainfall and the river. Due to falling heads and impacts on base flow to area streams, as well as prospects of subsidence, the regional water management plan calls for a reduction in pumping, limiting drawdown to 150 ft, and building surface water treatment capacity at a new water treatment facility. The regional authorities have committed to plan. Contamination is discovered in a portion of the aquifer (not all aquifers are interconnected) that connects to the regional water distribution system. The Trustees assert a large loss of extractive services, one requiring primary restoration of the plume computed as the volume of water to the full depth of the aquifer, as well as other restoration. The cost is several hundreds of millions of dollars.*

Similar to Case Scenarios 3 and 4, there is a high value placed on *in-situ* services and regional water policy reflects these. The water below the drawdown limit is not lost, and contamination does not disrupt the *in-situ* services. The remedy limits movement to streams, so there is no loss of ecological services. The regional is committed to a policy to limit pumping and build more surface treatment capacity. The small amount of water in the plume above 150 ft of depth and its associated sustained yield can be fully replaced by building a marginally larger treatment plant a little bit sooner. The cost is estimated at several hundreds of thousands of dollars.

4.2 Issues Raised by the Cases

It may seem that these hypothetical-but-realistic case discussions are designed to show that damages to ground water do not exist and are very small when they do exist. This is not the point of these discussions. Rather, they illustrate that main points of the paper: (i) damages need to be tied to service losses, (ii) service loss estimates need to account for the effects of the remedy and are measured from a baseline, which includes regional institutions for management of water; (iii) if services change, behavioral responses by water users which reflect substitution possibilities exist and are relevant to quantifying damages, (iv) economic methods for measuring damages should match how compensation will actually be paid, and (v) cost-effective compensation requires carefully matching the form and amount of compensation to the particular service losses identified.

The lesson is that the NRDA practitioner should determine where the contaminated water would have gone and what it would have done (i.e. the services it would have provided) absent the contamination; where it actually goes and what it does given contamination and the remedy. In so doing, the analyst should take into account that water is governed by many considerations, implying that services and their values are not uniform by geography or time, nor are they divorced from the institutional framework for water provision.

4.2.1 Extractive Services

When contamination affects extractive ground water services, the *potential* for service loss is clear, but *actual* service losses do not necessarily arise. The remedy may be effective in restoring (and/or preventing loss) of such services.

Case Scenario 5 is, in brief, the South Valley Superfund Site case in Albuquerque New Mexico (see Israel et al, 2017 for an overview). When the public supply well SJ-6 was taken out of service due to contamination, the cost of replacing pumping capacity by drilling a new supply well as part of the remedy was recognized by the Court. The Court noted that the replacement capacity allowed the City of Albuquerque to deliver water after the contamination at the same rate as before and hence that there was no loss of extractive services. Importantly the Court rejected the State of New Mexico's damage claims based on the cost of constructing and operating a reservoir (scaled by a REA-like "water storage for water storage" analysis), and considered that, if there was future demand for the contaminated water (say in an extended drought) and the pump-and-treat remedy had not yet fully restored the aquifer, wellhead treatment was a simple and cost-effective solution.[45]

Thus, in this important case, the Court's thinking rejected the application of water-for-water scaling *in favor of a more direct examination of service loss and cost-effective service replacement.*

The South Valley case also highlights the important role of institutions for water management in the measurement of damages. In that case, the role of the Rio Grande compact and the need for New Mexico to deliver water to downstream States was a crucial factor in the Court's determination that ground water services were not lost even if some ground water met criteria for injury determination. Any method that cannot respond to such institutional issues, such as a REA, that relies exclusively on a water metric, cannot provide an appropriate basis for scaling restoration in such situations.

2.2.2 Ecological Services

When ground water serves as a pathway to surface water environments, methods to address the resulting reduction in service provided by surface waters can be employed. These have been much-discussed in damage assessment (see, e.g. Dunford et al., 2004, and Desvousges et. al, 2018 on the use of service-to-service scaling of ecological losses at contaminated sites), and provide a basis for addressing the resulting surface water injuries directly, rather than *necessarily* through *ground water* restoration projects.

2.2.3 In-Situ Services

The final category of potential service loss is *in-situ* services. If the highest and best use of an aquifer is for subsidence avoidance or preventing salt-water intrusion to adjacent potable aquifers (as often is revealed by water management decisions that limit draw-down), contamination does not diminish these services. The volume or flux of water associated with the plume may be largely irrelevant (or worse, misleading) to injury quantification for these aquifers.

Three *in-situ* services not fully covered by the cases are: (i) holding water in storage as a "buffer value" or drought insurance against future supply disruptions, (ii) assimilative capacity and (iii) non-use service losses associated with existence values.

Buffer Values

Buffer values have been listed as *in-situ* services in some damage cases, as if it is some type of non-use service. While the buffer value of ground water is a recognized entity in the literature,[46] it is not really another source of value from holding water *in-situ*. It derives from a proper consideration of *future* extraction in current extraction decisions. Similar to so-called option values, the buffer value derives from a proper treatment of

[45] See *New Mexico v. General Elec. Co.*, 335 F. Supp. 2d 1185(D.N.M.2004); *New Mexico v. General Elec. Co.*, 335 F.Supp.2d 1157 (D.N.M.2004); *New Mexico v. General Elec. Co.*, 332 F. Supp. 2d 1237 (D.N.M.2004)

[46] See Tsur and Graham-Tomasi, 1992.

uncertainty associated with *use* of water through time and is not really a separate source of value apart from potential future use.

Waste Assimilative capacity
While I have seen assimilative capacity identified as a service loss, I have not seen it explicitly valued or used in formal scaling. Waste assimilation capacity is the ability of an aquifer to take up waste and store it, and perhaps lessen it by natural attenuation processes. The amount of service loss and its value are difficult to quantify; they depend on not just the aquifer's ability to supply these services from an aquifer (i.e. the physical capacity to assimilate wastes), but also the likelihood of the demand for these services (the actual use of the aquifer to assimilate wastes) being affected by the contamination at issue. Several considerations here require information beyond water volume.

One way to conceptualize this service is that "binding sites" for chemicals are in fixed supply and depletion of them causes an increase in a scarcity rent, rather like depletion of an exhaustible resource. Of course, if such binding sites are in excess supply, their marginal value is zero. Getting both the economics and the science right in this analysis would be critical to an accurate assessment. I cannot imagine data that would be readily available to reliably estimate a loss.

Non-Use Services in NRDA
In some ground water NRDAs, the issue of measuring non-use services and including them in the NRDA as WTP values lies squarely in the foreground. Measuring WTP for non-use values is controversial, and when included in damage assessments, debate as to the importance of non-use values and validity of methods for quantifying them will be contentious. In this section, I address these issues.

A vital distinction is between *substantive* understanding of non-use services of ground water, and the *operational* choices about whether and how to measure ground water values as WTP and include them in damage assessments. Non-use values – depending on how these are defined as discussed below – can only be measured using SP methods, as described earlier. This is because RP methods are based on observations of use, and so almost by definition cannot address non-use values. However, using SP methods to measure non-use values is controversial, and may result in unreliable estimates of WTP.[47] Thus, a deep difficulty seems to arise: if non-use values are important but only measurable with an unreliable method, what is better – some number or no number? It becomes important to examine carefully what set of substantive values is accurately measurable using RP methods and what is excluded from that set and only amenable to measurement using SP. Further, it is important to see if alternatives to SP exist for including non-use values in damage assessments.

I believe that, for most sites, using SP to measure non-use WTP values for ground water is questionable economic practice because:

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[47] See, for example, the studies collected in McFadden and Train (2017).

(i) A careful examination of the sources of value and methods for measurement reveals that much of what is claimed by some definitions to be a non-use value can be measured reliably using RP methods
(ii) The residual set of values, called "pure existence values" is a small fraction of the total value of ground water (this certainly is arguable);
(iii) Reliable measurement of pure existence values for ground water with RP methods will be extremely difficult and to date has not been demonstrated; and
(iv) Non-use values *are included in restoration-based approaches to damage assessment, and so the entire debate is largely unnecessary; reliable alternatives to SP that fully capture non-use values exist.*

The definitional issue is important here - definitions cannot be wrong, but they can be misleading. It is possible to *define* use values as attaching to an individual's current use of extracted water. Under this definition, all else is lumped together as non-use and is, demonstrably important; it is further true that an SP method could provide a WTP number for these values. If combined with an optimistic view of SP, the conclusion would be that the SP number is indeed better than no number. In my opinion this position is misleading and its reasoned basis flawed.

Consider ground water services *other* than current personal use. In-situ services other than existence services either are not affected (e.g. for preventing subsidence or salt water intrusion) or can be handled in other ways (e.g. potential loss of assimilative capacity). Ecological services losses can be addressed via use values (for direct and/or indirect human use) or a restoration-based approach with HEA or REA, which include non-use values for ecological services losses.

Ground water in storage for *future* use can be addressed using standard RP methods for extractive services, combined with a discount rate for adjusting future values to equivalent present values. The projection of future losses and values is a routine, if somewhat uncertain) component of NRDAs. So-called option values or buffer values are not non-use values; they refer to the proper analysis of use values under conditions of uncertainty in demand and/or supply. So far, there is no necessary reason to employ SP methods for non-use values.

Altruistic motives for non-use values may exist; these are preferences one person may hold that include regard for water use by others, now or in the future (bequest values). But a question arises as to whether they should be counted in a damage assessment, or whether to do so represents a double-counting (Milgrom, 1993). If you value my well-being, if I suffer a loss of ground water services, you feel my loss in addition to your own. But since I am compensated via the NRDA process, I suffer no net loss after compensation, and nothing need be added to your account to cover my (non-existent) loss. To do so is a double recovery.[48]

[48] If you have preferences regarding the *form* of my consumption, and so your altruism is paternalistic, this conclusion may break down, but it is not clear that such a loss (if it occurs at all) would be compensable in NRDA.

This leaves in the non-use category services consisting only of pure existence values that might arise independent of use of water by someone, sometime, under some condition. Pure existence values, if they exist at all, require an SP approach to be measured.[49] However, measurement of pure existence values is where reliability of SP is most questionable. Thus, we seem to face a conundrum of a potentially-important loss with no reliable way by which it can be measured

However, this difficulty only must be faced if the analyst ignores the availability of a restoration cost approach in which the restoration project compensates for *all* service losses, including non-use values. Irrespective of individuals' substantive motivations for holding potential non-use values, these are automatically included if a service-to-service approach is used and the water restored provides substantially similar services to the water injured.[50] Under the hypothesis that restoration costs are less than estimated WTP using SP, this is preferred and justified by economic theory (Freeman et al., 2014).[51] That said, the service-to-service methods require certain assumptions to be valid, and if these do not hold to a good approximation, the result can be biased estimation of restoration needs. On a case-by-case basis, one would need to consider the sources of the bias, the potential fixes for them. One may be required in these cases to undertake a detailed analysis of the potential competing imperfections of available methods.

5. SUMMARY DISCUSSION

Conducting a NRDA for ground water is a challenging exercise. This paper has addressed sources of particular challenges in the scaling of ground water restoration: the proper specification of baseline in all its guises, including the effects of the remedy and the overarching institutional context of water management; the foundational role of services provided by injured resources and by the chosen restoration; and the need to match services restored to those injured using an appropriate economic scaling method reflecting the chosen form of compensation.

The technical tasks undertaken by economists and scientists in support of the NRDA relate to the issue of scaling: how much restitution of the chosen kind is enough? The legal and policy environment in which these technical scaling analyses proceed set the boundaries and requirements of applicable scaling methods. Difficulties arise in the process when the selected scaling methods poorly match these requirements.

I have argued that the roles of services and baseline are fundamental as matters of logic, economic principles of compensation and valuation, and the NRDA process as articulated

[49] There is little to no evidence in the literature that pure existence values are relevant for ground water, as the vast majority of studies address willingness-to-pay to prevent health effects (see e.g. Bergstrom et al., 2001).

[50] To the extent that the manner in which water services are provided matters, so that a restoration project is seen as not equivalent to a natural process, then this may no longer hold; I think this would be difficult to untangle from a penalty for causing contamination in the first place, which is additional to natural resource damages.

[51] See Israel et al, (2017) for further legal analysis along these lines.

in the CERCLA regulations. Yet, the examination of actual cases across a variety of settings reveals that these ideas, even if articulated as important, are often improperly implemented in NRDA practice. It seems as if, once it has been determined that an injury has occurred, NRDA analysts act as if there is considerable freedom of choice of valuation or scaling methods, the details of which can bear only a tenuous relationship to the ground water services lost and gained from restoration and the real world institutions that govern how these services are provided. When scaling is divorced from institutional reality it becomes ethereal and speculative rather than grounded and concrete. This is when NRDA can go off the rails, leading to the wide disparity of approaches and results alluded to in the introduction.

It is the point of this paper that there is great benefit conferred by founding detailed assessment activities on a coherent technical framework that matches closely the actual facts of the potential gains and losses associated with the contamination and contemplated restoration. Thus, if the technical framework is too simple compared to the issues of concern, its benefit may evaporate and in fact may impede progress.

Unless the services provided by the restoration project closely match the types and magnitudes of service losses arising from the natural resource injuries, and both are roughly proportional to a water-based metric, the REA approach fails. There may be situations where the requirements hold. But such situations may be more the exception than the norm. Outside of these perhaps relatively unusual cases, use of a water flow or volume as a metric in a REA *assumes* rather than determines service loss, and leaps from injury determination (contamination in an aquifer) past the crucial step of identifying services lost and gained, directly to a mechanical computation of a restoration requirement.

A better approach for structuring most ground water assessments than water-to-water scaling is service to service scaling. In this approach, the suite of service losses on the injury side are carefully matched to the services gained via restoration in the scaling analysis. The primary implication of this distinction is that non-aquifer information typically must be employed to estimate service loss. People and institutions enter the equation, and the analyst must carefully "follow the water" to identify how water, institutions, and people interact and how this interaction is likely to have been changed by the combination of contamination/remedial action, and enhanced by restoration.

If by necessity or informed choice restored services are not the same as those injured, a carefully-estimated rate of trade between these is needed. This can usually be based on technical considerations or studies by RP valuation methods. Non-use values are deeply problematical. In my view, the service-to-service methods have great merit as a way to deal with them, even if they need to be enhanced to address potential violations of assumptions, and that this will almost always be a preferred path over SP techniques applied to non-use values for ground water.

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