DISSERTATION

VALUING ECONOMIC BENEFITS OF WATER'S ECOSYSTEM SERVICES WITH NON-MARKET VALUATION METHODS AND REGIONAL INPUT-OUTPUT MODEL

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Kawa Ng

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Doctoral Committee:

Advisor: John Loomis

Gregory Graff
Joshua Goldstein
Andrew Seidl

ABSTRACT

VALUING ECONOMIC BENEFITS OF WATER'S ECOSYSTEM SERVICES WITH NON-MARKET VALUATION METHODS AND REGIONAL INPUT-OUTPUT MODEL

Colorado has the highest trout angler participation rate in the United States, but the economic benefits of the state's anglers were last estimated more than two decades ago. Using survey data sampled in Colorado's stocked public reservoirs in 2009, Chapter one showed that trout anglers' net economic benefits were more than twice that of non-trout anglers'. Values estimated from Travel Cost Method produced angler day consumer surpluses of US$191.60 and $61.68 for trout and non-trout anglers respectively. Values from Contingent Valuation Method are $196.48 (trout) and $73.84 (non-trout) for the mean consumer surplus, while the median are $164.53 (trout) and $56.78 (non-trout). Thus the relative values of fishing for trout versus other species are robust to non-market valuation methods, and the two valuation methods show convergent validity.

Chapter two investigates the change in angler trips as a response to current season stocking level, in order to calculate the net economic benefit per fish stocked for selected hatcheries-stocked reservoirs in Colorado. Besides the unique objective to derive a marginal fish value for stocked trout in Colorado's reservoirs, this study also differs from

existing studies in that it does not arbitrarily assume the proportion of stocked fish caught by anglers. As an alternative, this study utilized the relationships among catchable trout stocking level, angler catch rate, annual trips and valuation estimates to derive economic values of stocked fish: $0.38 for trout and $1.88 for non-trout.

National forests contribute a substantial portion of water to the public supply in western states. In particular, units in the national forest system in Colorado are estimated to provide 68% of the water supply originating in Colorado in an average year. Chapter three used a customized value-added approach along with a state-wide input-output model to derive the marginal economic contributions to each economic sector in the state of Colorado. The approach used in this chapter differed from the traditionally applied method, in that it avoided over-estimating the value of water from implicitly assigning zero opportunity cost to all non-water inputs. Instead, the gross absorption coefficients for the water supply sector were used for adjusting the economic impacts. A method of calculating the economic contributions attributable Colorado's national forest water to each sector in the state economy was demonstrated. On an average year, summing across all sectors, water originating from Colorado's national forests contributed to a total of 4,738 jobs, $215,473,985 in labor income, and $264,485,290 in value-added for Colorado's economy.

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INTRODUCTORY CHAPTER

Economies and society as a whole rely on a suite of ecosystem services provided by water. Costanza et al. (1997) defined ecosystem services as flows of materials, energy, and information from natural capital stocks which combine with manufactured and human capital services to produce human welfare. These include nutrient cycling, waste treatment, pollination, biological control, refugia, food production, raw materials, genetic resources, recreation, cultural services, soil formation, sediment retention, erosion control, disturbance regulation, climate regulation, gas regulation, water regulation and water supply. It is an understatement to state that water is an important natural capital stock, since it touches every aspect of the natural / biotic environment and contribute to human welfare, therefore, the economic environment as well.

Besides the innate human need for water consumption, water also satisfies a wide range of domestic, commercial and industrial demands. Industrial sectors use water as an input in their production process. Substantial amounts of water are required for the production of commodity such as food, paper, chemicals, refined petroleum, or primary metals; while other industrial sectors demand water for manufacturing, processing, washing, diluting, cooling or transporting a product (Kenny et al. 2009). Water is also used for irrigated crops, mining, power generation, livestock watering, washing, flushing, food preparation, gardens and lawns, and firefighting. In other cases, water either directly or indirectly support specific activities, for example, by irrigating golf courses, providing scenic backdrop, filling reservoirs and lakes in the park, swimming pools, fish hatcheries, and supporting boating, angling or other water related recreational activities.

Albeit exceptionally valuable, benefits from water resources are difficult to value quantitatively (i.e. to monetize). When making natural resource management decisions, information on the economic benefits of resources such as water are especially useful. Nevertheless it is frequently the case that water is under-priced and under-valued, or not valued at all. Chapter 3 begins by first explaining this paradox, then, the value-added approach is used along with a state-wide input-output (I-O) model to derive the marginal economic contributions of water to each industry in the state of Colorado. Chapter 3 also demonstrates a method of estimating water withdrawals for all sectors in Colorado's economy as well as calculating the economic contributions attributable to water originating from national forests in Colorado. In this study, attentions are given to forest within the National Forest Systems, which is owned and managed by the U.S. Forest Service: this is due to the fact that units in the national forest system in Colorado are estimated to provide 68% of the water supply originating in Colorado in an average year (details are provided in Chapter 3).

Besides economic contributions to industries, there are values from water that are not accounted for in the market. Since those benefits are not the result of market transaction, they are not reflected as final demand in I-O models, such as the one used in Chapter 3 of this dissertation. These include a whole suite of ecosystem services mentioned in the first paragraph, and, ignoring them can produce a biased or incomplete view of water resources. While chapter 3 shows a method of calculating the economic contribution of water to industries (production value of water), the rests of this dissertation estimate one of the cultural aspect of water's ecosystem service that is not accounted for in the market: recreation.

Valuation of recreational benefit is an interesting crossroad. On the one hand, the economic impacts to local sectors from recreationists' spending are customarily estimated using I-O models, and results are expressed in terms of number of jobs, labor income, output and value added as a direct and indirect result of the visitor spending. On the other hand, this approach does not capture the benefits visitors receive from the recreational experiences itself. Non-market valuation methods are designed to elicit this type of benefits. Chapter 1 and 2 explain some of these non-market valuation methods, and employ the travel cost model to estimate the non-market value of angling in Colorado's hatchery-stocked reservoirs.

Angling in Colorado's hatchery-stocked reservoirs is an activity that relies greatly on both water and forests in the state (the intricate relationships between Colorado's forests and water supply are explained in the next chapter). Firstly, many anglers in Colorado use a boat; therefore the qualities, as well as the possibility of the recreational experience itself rely upon the water level in the reservoir. To be specific, forests support the recreation experience of anglers via their water regulation services, even when the angling activity does not take place in a forested setting. By having intact and functioning forests ecosystems, water's sedimentation and turbidity level are controlled naturally; furthermore, it prevents flows (from precipitation and snow melts) from releasing in big surges instead of in a desirable, timely and gradual manner. For these reasons, forests ensure water flow's timing and quality, thus providing pleasant recreation experiences for anglers fishing in the stream (where having too high or too low in streamflow affect the fishing) as well as those fishing on the banks of reservoirs (where low water level diminish, and in some case prevent the recreation experience, more details in the concluding chapter). As mentioned above, hatcheries also require water to operate. Although not a focus of this dissertation, having water supply of high quality as a production input can reduce the operating cost (reduce the need for water treatment and sediment removal) of hatcheries.

Hatcheries across the U.S. overwhelmingly raise trout species (details in Chapter 1), which are then stocked in public waterways by state and federal wildlife management agencies. In estimating the non-market value of angling in Colorado's publically stocked reservoirs, Chapter 1 also compares trout anglers' net economic benefits with non-trout anglers'. Chapter 2 in turns investigates the change in angler trips as a response to current season stocking level, in order to calculate the net economic benefit per fish stocked (trout and non-trout respectively) for selected hatcheries-stocked reservoirs in Colorado.

Figure 1 below conceptualizes the overall dissertation in the framework of water's ecosystem services valuation. While the overarching theme of this research is the economic benefits of water in Colorado (first column of figure 1), through the ecosystem services' perspective, there is no single overarching value that one can monetize or summarize. The concept of service flow matters. What kinds of benefits, benefits to what and to who matter. The second column lists the four main categories of ecosystem services: provisioning, supporting, cultural and regulating services (Millennium Ecosystem Assessment 2003). Provisioning is the type of service most familiar to all when it comes to the benefits of water: drinking water and intermediate use of water as input for industrial / commercial production. Figure 1 links chapter 3 of this dissertation to this category. As for water's cultural services, any activities supported by the quality or quantity of water level / stream flow, as well as the access / existence of traditionally important body of water, all provide benefits to human. Outdoor recreational activities are the most often cited example for the cultural aspect of ecosystem services. The first two chapters derive the non-market value of this service from the view point of recreational anglers in Colorado, by examining the relationships between target species, catch rate and stocking intensity. The dashed-line between provisioning service and chapter 1 / 2 signifies that if anglers consume their catch, water level supporting recreational angling also supports the provision of fish as food.

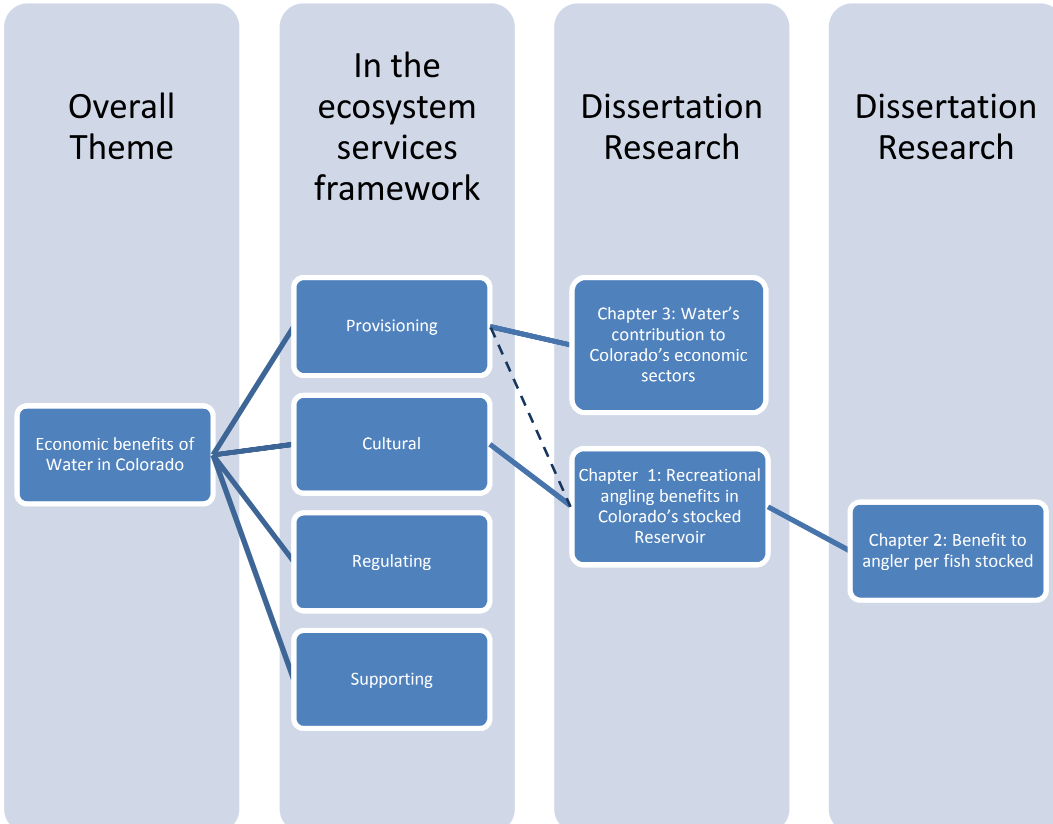

Figure 1.Concepulization of dissertation in the framework of water ecosystem services

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CHAPTER 1

COMPARING ECONOMIC VALUES OF TROUT AND NON-TROUT ANGLERS IN COLORADO'S PUBLIC STOCKED RESERVOIRS

1.1 Background

Anglers worldwide frequently fish for a variety of trout species such as brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss*. Angler studies in Australia, Canada and Chile have reported trout being the most frequently caught fish (DOF 2002; GSGislason & Associates 2009; Arismendi and Nahuelhual 2007). In the USA, 6.8 million Americans 16 years or older fished for trout in 2006 (Harris 2010), while over 90% of anglers reported that they targeted trout in Minnesota, Wisconsin, Iowa, Illinois, Oklahoma, and Colorado (Hart 2008; Prado 2006; USFWS 2007). It is of no surprise that brown and rainbow trout have respectively been the top two most commonly introduced game fish species in the USA (Rahel 2000). In 2004, the U.S. Fish and Wildlife Service's top 11 hatcheries (with > 15,000 lb. annual production) stocked 9.4 million rainbow trout across the USA, out of which 1.2 million were stocked in Colorado, making it the second (behind Arkansas) most stocked state (USFWS 2007). Besides popularity, there are also economic benefits associated with stocking trout. Economic benefits from recreation such as fishing can generally be expressed in terms of economic impacts (jobs, incomes, retail sales generated from angler activities) and / or 'net economic benefits' (anglers' willingness to pay for their recreational experience, in additional to trip costs such as gas and lodging). Rainbow trout-related federal hatcheries budget expenditures totaled US$5.4 million in 2004 for the USA (USFWS 2007). Spending from recreational trout anglers also supported over 100 thousand jobs and generated $13.6 billion in economic output in 2006 (Harris 2010).

Despite having the highest trout angler participation rate in 2006 out of all 50 states (Harris 2010), Colorado's anglers' economic values were last estimated in the late 1980s (Harris 1983; Johnson 1989; Harpman et al. 1993; Johnson et al. 1995). All of these older studies sampled river anglers except for Johnson's 1989 study, which included one reservoir in Colorado. However, almost all rainbow trout raised by federal hatcheries in Colorado were released in reservoirs, lakes and ponds, and 68% of all anglers in Colorado were reported to fish most often at reservoirs, lakes and ponds (USFWS 2007; CDOW 2005). Given the above, an updated economic study on Colorado trout anglers that focuses on heavily stocked reservoirs is warranted, especially given the substantial population growth in Colorado since the 1990s.

1.1.1 Literature review on species specific estimates

Willingness to pay (WTP) is the measure of economic benefits, or consumer surplus, to anglers in excess of or in addition to their trip costs. This measure of value to anglers is used in benefit-cost analysis by federal agencies such as U.S. Army Corp of Engineers and the Bureau of Reclamation (US Water Resources Council 1983).

In the non-market valuation literature, ample efforts have been placed on investigating factors affecting WTP results such as methodology and respondent / resource use characteristics. In the field of recreational fishing, naturally, the intriguing question becomes: do anglers' WTP vary according to target species? Drawing motivation from the background section of this paper, we are interested in revealing how WTP estimate for trout compares with other target species.

Some studies have found that anglers' marginal value per trout is *less* than other species of fish (Boyle et al. 1998; Lupi et al. 1997; Murdock 2001). While others have found trout to have a *higher* marginal value to the angler than other species (Vaughan and Russell 1982; Loomis 1988; Olsen et al. 1991; Besedin et al. 2004). The U.S. Fish and Wildlife Service (USFWS) showed that from their 2001 national fishing survey, trout anglers had higher net economic values across the board (Aiken and Pullis La Rouche 2003). From the 2006 survey however, trout had higher net economic values for out-of-state anglers only; while for in-state anglers, values were higher for bass *Micropterus salmoides / M. dolomieui* and walleye *Sander vitreus*. Both USFWS surveys employed Contingent Valuation Method (or CVM, to be explained in the next section).

In an attempt to search for systematic determinants affecting angler WTP, Johnston et al.'s (2006) meta-analysis showed that anglers' WTP for trout were generally lower than other target species, but they cautioned that this species-specific effect could be confounded with other methodological effects regarding valuation methods. So this seemingly species-specific effect might actually be methodological, or study-specific. An opportunity to test, and provide more evidence for species-specific effect would require estimating WTP for two groups of species in a single study, using more than one valuation method.

Our study contributes to this literature by (1) providing an up-to-date Colorado estimate of WTP for trout fishing in stocked reservoirs and (2) comparing the values of trout fishing and non-trout fishing using two different valuation methodologies (travel cost and contingent valuation methods) to test if any ordering in species values is robust to valuation method. If these two different valuation methods yield statistically equivalent set of WTP for trout fishing relative to other species, this would demonstrate that the two valuation methods have convergent validity.

1.1.2 A review on methods and models

Since the benefit from partaking in a recreational trip is more than the expenditures for the trip, non-market valuation techniques are required to estimate the WTP of recreational experience such as fishing. Over 400 studies on the economic values of recreational fishing have been documented (Johnston et al. 2006). Studies estimating the recreational values of fish (or for an angler day) have employed different variations of Travel Cost (TCM) and Contingent Valuation (CVM) methods.

1.1.3 Travel cost method

Travel Cost method uses the spatial variation in travel cost as a proxy for price, and variations in the number of trips taken in responses to the spatial variation in price to estimate anglers' demand curve. From the demand curve the WTP or Consumer Surplus is calculated. TCM studies' approaches ranged from single site individual TCM with Ordinary Least Squares (OLS) (Martin et al. 1982), zonal TCM with generalized least squares (GLS) (Vanghan and Russell 1982), multisite TCM (Loomis 1988), as well as nested random utility models (RUM) (Lupi et al. 1997; Murdock 2001). When valuing outdoor recreation, Poisson regression is a standard method to model count response data such as the number of trips taken by anglers. Since in this study we modeled angler visitation counts using on-site sampling data (to be explained in the next two sections), it is helpful to first review the common problems associated with this method here.

As count models gained popularity in recent years, different forms emerged in order to deal with issues surrounding the nature of estimating values from count data such as overdispersion (Hilbe 2007), and especially when on-site sampled data were used (Shaw 1988). Consequently, recent studies rarely use the unmodified Poisson model to estimate recreational values of anglers.

Truncation arises in TCM when the response variable is truncated at one trip, since on-site sampling does not target non-users. This problem can be addressed using the truncated Poisson regression model (Shrestha et al. 2002). Negative binomial models are often used to address overdispersion, where the variance in numbers of trips is larger than the mean, as in Chizinski et al. (2005). Recent studies have addressed both truncation and overdispersion together using a truncated negative binomial count model (Kerkvleit et al. 2002; Oh et al. 2005; Arismendi and Nahuelhual 2007; Prayaga et al. 2010).

A third problem, endogenous stratification, occurs where on-site sampling resulted in having a higher chance of encountering avid users. This has been recognized and dealt with in recent recreational fishing literature, along with all of the above-mentioned issues, using an endogenously stratified truncated negative binomial model (Curtis 2002; Prado 2006; Ojumu et al. 2009). It has been shown that accounting for endogenous stratification in a count data specification lowered the benefit estimate (Martínez-Espiñeira et al. 2006). Studies have also showed that benefit estimates were further reduced after *also* correcting for truncation (Loomis 2003) and allowing for overdispersion

(Martínez-Espiñeira et al. 2008). We will employ a model correcting for truncation as well as endogenous stratification in this study.

1.1.4 Contingent valuation method

Contingent Valuation (CVM) is also a widely used method for estimating recreational fishing's benefits. Contingent Valuation is a stated preference method that uses survey questionnaires to directly elicit anglers willingness to pay (WTP) for their recreation experience. This method is approved for use by federal agencies to perform benefit-cost analysis (US Water Resources Council 1983). It provides the flexibility to elicit angler's WTP for a proposed change in trip, environmental, site or catch qualities. Dichotomous choice (Yes / No) has been a popular WTP elicitation format in CVM studies (Brooks 1990; Wheeler and Damania 2001).

1.1.5 Convergent validity

Studies that have used both CVM and TCM offer an opportunity to test the convergent validity of such non-market valuation methods. The hypothetical nature of CVM is often a source of concern (Bateman et al. 1995; Loomis 2011). For instance, Williams and Bettoli (2003) used two-stage demand zonal TCM and dichotomous-choice Logit CVM to estimate trout anglers' WTP in eight Tennessee rivers, and found that values estimated from CVM exceeded TCM's (as much as nine-fold on one site). Nevertheless, others have found the opposite. In an Idaho's warm/cold and steelhead fisheries study, Sorg and Loomis (1986) reported larger values using TCM as opposed to

CVM. Also in Hartwig's (1998) angler study in Virginia, angler values generated from TCM were greater (more than double on some sites) than those from CVM.

We will estimate the consumer surplus in terms of an angler day in Colorado, using both TCM (Poisson count models correcting for on-site sample biases) and CVM (dichotomous choice Logit model) to evaluate convergent validity of the two methods. These are newer methods than what have been used in past studies. We present results for both trout and non-trout anglers respectively.

1.2 Empirical methods used in this study

1.2.1 The travel cost model

To model non-negative integer responses such as the number of trips taken annually by anglers, the Poisson count data regression model is used as the starting point (Greene 1992; Cameron and Trivedi 1998):

$$\Pr(\mathit{ANNUAL\ TRIPS}_i = \mathit{Annual\ Trips}_i) = \frac{e^{-\lambda_i}\lambda_i^{AnnualTrips_i}}{AnnualTrips_i!},\ \mathit{Annual\ Trips}_i = 0, 1, 2\ldots \quad \textbf{(1.1)}$$

The response variable *ANNUAL TRIP* is the self reported annual number of trips taken to the fishing site and has a Poisson distribution with conditional mean and variance equal to λ_i = exp($\mathbf{x_i}$ $\boldsymbol{\beta}$). The vector of independent variables $\mathrm{x}_\mathbf{i}$ include *PTOTAL_GAS* – the per person cost of gasoline for car and / or boat incurred on the trip, *CATCHPERHOUR* – the self-reported catch divided by hours fished, *USE_MOTOBOAT* – dummy variable on whether the anglers used a motorized boat on their fishing trip, *NUM_PARTY* – the number of adult and child traveling in the group, *PAYING_HOUSEHOLD* – the number of household member(s) contributing to the angler's household expenses, *EDUCATION* – indicates the angler's highest level of formal education, and *TRIP_OTHERSITES* is the number of trips taken to all fishing sites during the past year, other than the one currently on. This is a proxy for the composite price of substitutes available (Smith 1993).

Since our sampling occurred on-site (details on the survey instrument and data are in the next section), one is more likely to encounter anglers who fish more frequently than those who rarely fish. This can result in over-sampling of avid anglers. To account for this endogeneity as well as the problem of zero-truncated samples, we subtracted one from each response variable *ANNUAL TRIP* (Englin and Shonkwiler 1995; Loomis 2003).

The Poisson count model regression is specified as:

$$\begin{aligned}(\text{ANNUAL TRIP} - 1) = (\exp(\beta_0 + \beta_1\,&\text{PTOTAL\_GAS} + \beta_2\,\text{CATCHPERHOUR}\\ &+ \beta_3\,\text{USE\_MOTOBOAT} + \beta_4\,\text{NUM\_PARTY}\\ &+ \beta_5\,\text{PAYING\_HOUSEHOLD} + \beta_6\,\text{EDUCATION}\\ &+ \beta_7\,\text{TRIP\_OTHERSITES}) + e. \qquad \textbf{(1.2)}\end{aligned}$$

In the remainder of the paper we call this the Truncated Endogenous Stratification Poisson, or TESP model. Note that our model does not include any variable for travel time. We tried this as a separate variable, but due to its high correlation with *PTOTAL_GAS*, it made *PTOTAL_GAS* insignificant and therefore the TCM was not useful for calculating WTP.

The mean net willingness to pay (WTP) per trip is simply the inverse of the estimated travel cost coefficient $\beta 1$.

$$\text{Net WTP} = 1 / -\beta_1 . \qquad \textbf{(1.3)}$$

The 90% confidence intervals are calculated using the cost variable's standard error:

$$\text{CI} = 1 / (|\beta 1 +/- 1.645 * \beta_{1\,SE}|). \qquad \textbf{(1.4)}$$

1.2.2 The contingent valuation method

Our survey used the dichotomous choice elicitation format to ask anglers whether they would or would not to pay a pre-determined increase in the cost of their trip. Each angler responded to only one bid amount, but that dollar amount varied across the sample of anglers.

The binary response variable *BID CHOICE* is the angler's decision (1 = yes, 0 = no) on whether to still make the trip given an increase in trip cost (*BID AMOUNT).* The other independent variable included is *CROWDED*, which is an index of perceived crowdedness (1 = not crowded at all, 10 = extremely crowded). This is to gage respondents' trip experience and a proxy for satisfaction, which is an important aspect in CVM. We modeled anglers' decision with the following logit model:

$$\text{Ln}\left(\frac{P(BID\_CHOICE=1)}{1-P(BID\_CHOICE=1)}\right) = \hat{a}_0 + \hat{a}_1\, BID\ AMOUNT + \hat{a}_2\, CROWDED + e. \qquad \textbf{(1.5)}$$

The mean and median WTP values are calculated with the explanatory variable's sample mean:

$$\text{Mean WTP} = (1/ -\hat{a}_1) * \ln (\exp (\hat{a}_0 + (\hat{a}_2 * \overline{CROWDED})) + 1). \quad \textbf{(1.6)}$$

$$\text{Median WTP} = (\hat{a}_0 + (\hat{a}_2 * \overline{CROWDED})) / -\hat{a}_1 . \quad \textbf{(1.7)}$$

We ran each model (TCM's Poisson and CVM's Logit) for the trout angler's samples and non-trout angler's separately, in order to test our first hypothesis of whether benefits from two different species are equal. Employing both revealed preference TCM and stated preference CVM to estimate the value of anglers WTP offer an opportunity to test the convergent validity of such non-market valuation methods. Our second hypothesis is to check whether or not the WTP values from TCM would be reasonably similar to CVM's. Lastly, we can then determine if ordering of species values is robust to valuation methods.

1.3 Data collection and study areas

Mail-back questionnaires were used to collect information needed for estimating the values of an angler day in Colorado's publicly stocked reservoirs. We intercepted both shoreline and boat anglers at parking lots, boat ramps / zebra mussel *Dreissena polymorpha* inspection points, marinas and reservoir banks. We handed out mail-back survey packages containing a cover letter, questionnaire, and a stamped and addressed envelope. A total of 511 surveys were handed out during 23 sampling days from July to mid-September in 2009 (a mix of weekdays and weekends, including 4th of July and Labor Day weekends) at 11 reservoirs in Colorado. These reservoirs are located along Colorado's Front Range (Martin, Horseshoe and Pueblo reservoirs) and the Western Slopes (Blue Mesa, Crawford, Ridgway, Lake Granby, Grand Mesa Lake, Steamboat, Rifle and Harvey Gap reservoirs). Species available to anglers include brown *Salmo trutta* and rainbow trout *Oncorhynchus mykiss*, black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus*, channel catfish *Ictalurus punctatus*, smallmouth and largemouth bass, saugeye (sauger *Sander canadensis* x walleye *S. vitreus*), sauger, splake (lake trout *Salvelinus namaycush* x brook trout *S. fontinalis*), wiper (white bass *Morone chrysops* x striped bass *M. saxatilis*), tiger muskie (northern pike *Esox lucius* x muskie *E. masquinongy*) and kokanee salmon *Oncorhynchus nerka*. The 11 reservoirs sampled were among the most heavily stocked public water bodies by state and federal hatcheries in 2009. All of them required entrance fees except for Blue Mesa reservoir, which is in a National Recreation Area, and is free of charge. There were only two on-site refusals during the entire sampling season. After postcard reminders and a second mailing, 265 completed and usable surveys were returned by October, resulted in a 51% response rate.

Each household / party received only one survey, and was asked that only one adult angler to fill out the survey. The questionnaire first asked the number of trips in the past 12 months he or she made to the reservoir where they received the survey. This is the response variable (*ANNUAL TRIP*) for our TCM Poisson model. The anglers then provide information regarding their current fishing trip such as the species of fish they were targeting, the number of day(s) spent on the trip, the amount of time spent fishing, the number of trips taken to other fishing sites besides the one they are currently on, the number of fish caught, other non-fishing activities participated, the primary purpose of their trip, and attitudinal information. The attitudinal questions include the angler's perceived level of crowding at the reservoir they visited. The questionnaire then elicits the dollar amount spent on the trip for the whole household / party by asking the respondent to indicate the amount they spent on fifteen different categories (from gas, food, supplies, fishing license to camping / hotel costs), and the number of persons sharing expenses on the trip. This allowed us to calculate the per angler expenditure. After eliciting anglers' expenditures, the next question is the dichotomous choice CVM question, it asked:

> As you know, some of the costs of travel such as gasoline, hotels and restaurant meals often increase. If your share of the total cost of this most recent trip had been $XX.XX higher, would you have made this trip to the water body where you received this survey?
> Circle one: YES NO

As mentioned in the CVM section above, the dollar amount assigned ($XX.XX) varied across the sample, which ranged from $5 to $2,000. We expected this range to produce a consistent downward sloping demand curve, since most anglers would pay $5 more per trip and refuse to pay a $2,000 increase in costs. The anglers' decision (*BID CHOICE*: 1 = yes, 0 = no) and dollar amount faced (*BID AMOUNT*) would constitute our CVM model's response and explanatory variable respectively. Our CVM question is like most others and focuses on the most recent trip. However, it may be that if anglers faced his higher cost on all trips they would take fewer trips.

1.4 Results

The sample size for the TCM and CVM analysis is 232 as we included only those respondents that stated visiting the reservoir was their primary purpose of the trip or, one of many equally important reasons (thus excluding incidental trips). This is a necessary sample adjustment to ensure that trip costs can be attributed to fishing at the reservoir, and not some other site or activity. Out of which 137 anglers targeted trout (exclusively or along with other species), while 94 anglers did not target trout on their fishing trip. Table 1.1 presents variables definitions and summary statistics while figure 2 compares trip preferences between the two anglers groups.

Table 1.1 Variables definition and summary statistics (means and medians) by target species

Variable	Definition	Trout anglers		Non-trout anglers	
		Mean	Median	Mean	Median
CATCHPERHOUR	Hourly catch rate (*TARGET_CAUGHT/FISHHOURTRIP*)	0.86	0.5	0.82	0.33
USE_MOTOBOAT	= 1 if angler used a motorized boat for fishing	0.41	0	0.81	1
DAYPERTRIP	No. of days spent on trip	2.94	2	4.18	2
SHARE_EXPENSE	No. of people sharing trip expenses	2.05	2	1.81	2
NUM_PARTY	No. of individuals in angler's group	4.36	3	4.12	2
PAYING_HOUSEHOLD	No. of household member(s) contributing to the angler's household	1.88	2	1.76	2
TARGET_CAUGHT	No. of target species caught per trip	5.86	3	7.52	3
ANNUAL TRIP	No. of trips to the reservoir in last 12 months	4.2	2	5.96	4
CROWDED	Perceived Crowdedness Index (1 to 10, 10 = extremely crowded)	4.05	3	4.59	4
EDUCATION	Highest level of formal education obtained (1=elementary, 6=graduate school)	4.32	4	4.03	4
FISHHOURTRIP	No. of hours spent fishing on trip	9.39	6	11.37	8
TRIP_OTHERSITES	No. of trips to other fishing sites in last 12	12.43	9	11	23.95
PTOTAL_GAS	Dollar amount (2009 USD) spent on gasoline per person	$49.57	$25.00	$57.71	$40.00
PTOTALCOST	Dollar amount (2009 USD) spent per person during the trip	$195.76	$112.00	$167.72	$117.50

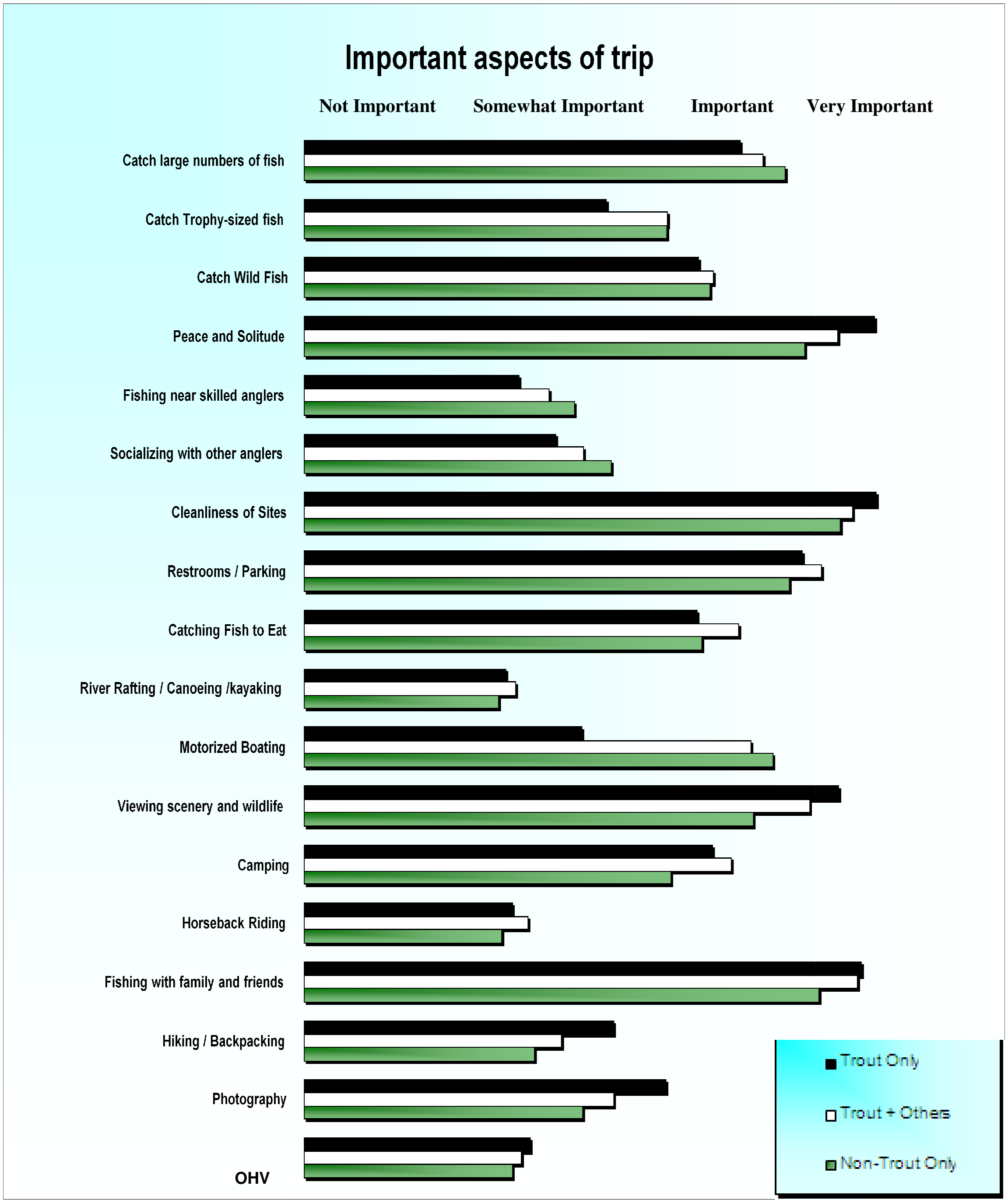

Figure 2. Important aspects of trip as reported by trout and non-trout anglers

From the summary statistics in Table 1.1, trout anglers took fewer trips in the past 12 months, took shorter trips, fished fewer hours, caught less fish per trip, less likely to fish on a boat, felt their fishing sites were less crowded, and individually spent less money on gasoline compared with non-trout anglers. However, trout anglers came with a larger group, and have more members sharing trip expense (household expense as well). Additional insights are shed regarding the demarcation between two anger groups in figure 2. In the survey questionnaire, respondents were asked to rank how they feel about 18 different trip aspects in terms of 'not important', 'somewhat important', 'important', or 'not important'. Figure 2 shows catching large numbers of fish, trophy size fish, wild fish, and catching fish to eat are trip attributes that were relatively less important to trout anglers. Trout anglers also felt that it was less important to be around skilled anglers, socializing with other anglers, or using a motorized boat on their trips. On the other hand, trout anglers stated that while on their trips, it was more important to find peace and solitude, having clean facilities, adequate restrooms / parking, spending time with family and friends, as well as being able to participate in other activities such as wildlife viewing, camping, horseback riding, hiking, backpacking, photography and OHV riding. In other word, trout anglers can be viewed as 'generalists', where fishing is a part of their overall recreation experience; while non-trout anglers are 'specialist', where they partake on an angling trip more often annually (also spend more days per trip), and placed the act of catching fishing itself on a relatively higher place. The implication of this is apparent and will be discussed in chapter 2.

As mentioned in previous sections, count data generated from on-site sampling often do not conform to the standard Poisson distribution. We addressed zero truncation and endogenous stratification together with the TESP (Truncated Endogenous Stratification Poisson) model. We performed Z-score tests to confirm that negative binomial is not preferred over the standard Poison distribution for our data. Another potential violation of Poisson distribution is over-dispersion. A Z-test to evaluate whether the amount of overdispersion in a Poisson model is sufficient to violate the basic assumptions of the model was performed. All our models resulted in large Z-scores (> 2,000) with t-probabilities > 0.05. Since this tests whether the data should be modeled as Poisson or negative binomial, this indicates that we failed to reject the hypothesis of no overdispersion (Hilbe 2007). Therefore, it is likely that real overdispersion does not exist in the data.

The Aikaike Information Criterion (AIC) is a measure of model fitness, smaller values suggest a better fit. Results indicate that the TESP model is a better fit (for trout models: AIC = 6.01 and 5.93 for Poisson and TESP models respectively; for non-trout models: AIC = 7.58 and 7.53). Table 1.2 shows regression results for the TESP models.

Table 1.2 Travel cost (TCM) truncated endogenous stratification Poisson (TESP) regression results by target species

Variable	Trout anglers	Non-trout anglers
PTOTAL_GAS	-0.0018	-0.0039
(standard error)	(0.0009)*	(0.0009)**
TRIP_OTHERSITES	0.0263	0.0032
	(0.0031)**	(0.0006)**
USE_MOTORBOAT	0.3955	0.6002
	(0.0994)**	(0.1439)**
NUM_PARTY	-0.0731	-0.0526
	(0.0193)**	(0.0181)**
PAYING_HOUSEHOLD	0.3219	-0.1818
	(0.0639)**	(0.0931)*
EDUCATION	-0.1658	0.0950
	(0.0466)**	(0.0439)**
CONSTANT	1.0307	1.2856
	(0.2605)**	(0.3223)**
N	135	93
McFadden's R2:	0.1805	0.124
Z-Score	2061.3	47437.3
Z-Score (p > |t|)	0.257	0.162
* significant at 5%; ** significant at 1%		

All variables in the TESP models are significant to at least 5%, except for *CATCHPERHOUR,* which also happened to be correlated with *TRIP_OTHERSITES.* Since the number of trips to other sites serves as an important proxy for substitution in our models, *CATCHPERHOUR* is subsequently dropped. Most of the regression coefficients signs are consistent across both trout and non-trout models: anglers take fewer trips when they come with larger groups, or when faced with higher travel cost; on the other hand, the number of trips taken to other sites and using a motorized boat are positively correlated to annual trips. The signs for the number of people paying household expenses and education level are not consistent across both types of anglers.

Table 1.3 presents results from CVM Logit regressions. As expected, the dollar amount of the increase in trip costs (*BID AMOUNT*) is significant, and negatively correlated with anglers' decision on whether or not to still make the trip. The level of perceived crowdedness is negative and significant for trout anglers but not for non-trout's. This tied in perfectly with results shown in Figure 2, where trout anglers revealed they felt that 'peace and solitude' was a relatively more important aspect of their trip compared with non-trout anglers. This not only confirms the CVM model results (the sign and significance of the *CROWDED* variable between two angler groups), but also reaffirms the importance of including the *CROWDED* variable in the regressions. Since CVM models ex ante decision, the survey question in effect asked the respondents: 'given the experience you just had, would you have paid more for it?' In the model results shown in Table 1.3, the question was extended to: 'given the experience you just had, would you have paid more for it? Was crowdedness a factor that influenced your decision?' So the crowded variable can be a good proxy for anglers' 'happiness', therefore very important to stated preference methods such as CVM.

Table 1.3 Contingent valuation (CVM) Logit regressions results by target species

Variable	Trout anglers	Non-trout anglers
BID AMOUNT	-0.0026	-0.0043
standard error	(0.0006)**	(0.0011)**
CROWDED	-0.1923	0.0092
	(0.0804)*	0.1019
CONSTANT	2.0511	0.9804
	(0.4556)**	(0.5886)*
N	127	87
Pseudo R-squared	0.2375	0.2969
* significant at 5%; ** significant at 1%		

1.4.1 Angler day benefits estimates

Applying equation (1.3) and (1.6), we present the net WTPs for both trout and non-trout anglers from the TCM and CVM models in Table 1.4.

Table 1.4 Angler day consumer surplus (2009 USD) calculations from travel cost (TCM) and contingent valuation (CVM) models by target species.

	TCM		CVM	
	Trout anglers	Non-trout anglers	Trout anglers	Non-trout anglers
Mean net WTP per trip	$563.79	$257.86	$577.65	$308.71
Median net WTP per trip			$483.72	$237.38
Mean net WTP per angler day 90% CI	$191.60 ($106 - $988)	$61.68 ($44 - $102)	$196.48	$73.84
Median net WTP per angler day			$164.53	$56.78

Since the gasoline cost from the TCM models (*PTOTAL_GAS*) and the amount of expense increase from the CVM models (*BID AMOUNT*) are per angler trip cost, it is necessary to divide the net WTP estimates by the mean number of days per trip (from Table 1.1) to get the angler day values. Angler day values obtained from TCM are only slightly lower than CVM's mean angler day values (TCM > CVM by $5 and $12 for trout and non-trout anglers). This suggests there is some degree of convergent validity between the two valuation methods. Both methods consistently revealed that angler day benefits for trout fishing are almost three times higher than non-trout's. In fact, in the TCM model, trout and non-trout angler day value estimates' 90% CI did not overlap. The finding of trout per angler day benefits being higher than non trout in both CVM and TCM suggests this finding is robust to valuation method.

1.5 Conclusion

We used data from a 2009 angler survey sampled at 11 publicly stocked reservoirs in Colorado to estimate the values of trout versus non-trout anglers by using both Travel Cost (Poisson count models correcting for truncation and on-site sample biases) and Contingent Valuation (dichotomous choice) methods. Both methods revealed that benefits from trout anglers are consistently higher than non-trout's. After correcting for truncation and endogenous stratification, TCM models produced an angler day benefit of $191.60 for trout anglers and $61.68 for non-trout anglers. While CVM produced the mean angler day benefits of $196.48 and $73.84 for trout and non-trout anglers, respectively. CVM's median values are $164.53 and $56.78. The similarity of mean WTP estimates between TCM and CVM demonstrates convergent validity and that ordering in species values is robust to valuation methods. Perhaps one reason this study showed such close correspondence between TCM and CVM WTP values is that the same anglers were asked in the same survey to provides data for both methods. Furthermore, results and evidence for convergent validity in this chapter cannot be viewed as another drop in the same 'inconsistent / past result' bucket. As motivated in the objective and literature review section, the apparent differences in the ordering of species valuation comes from a number of individual studies, all at difference locations, some valuing only one species at a time, and meta-analysis have also pointed out that they could be due to methodological differences. In contrast, this study used the same survey instrument at the same sets of reservoirs in Colorado, via two difference valuation methods. Also when comparing the ordering of species value, a substantial amount of the marginal per fish value shown in the review section was not directly calculated in the original studies, rather they were calculated by Johnston et al (2006) from information in the studies compiled. On top of this, Johnston et al. noted "some studies evaluated WTP for groups of species that did not fit cleanly into one of the aggregate species groups (trout vs. Salmon vs. bass, etc.). In those cases, the groups of species from the study were assigned to the aggregate species group with which they shared the most species." In contrast, the analysis in this dissertation explicitly models the two species separately in order to compare and contrast, but still used data collected from the same instrument.

The conventional convergent validity tests have the simple hypothesis of $WTP_{TCM} = WTP_{CVM}$ for the same goods. This study implemented a more demanding convergent validity test of valuation method, requiring consistency across types of method as well as resources valued. In effect, our hypothesis tested is $(WTP_{(trout)TCM} = WTP_{(trout)CVM}) > (WTP_{(non\text{-}trout)TCM} = WTP_{(non\text{-}trout)CVM})$. This consistency allows us to claim validity for the general hypothesis that $WTP_{trout} > WTP_{non\text{-}trout}$. Nevertheless, we acknowledged that our sample size is rather small, and our survey focused on reservoir anglers in Colorado. Similar studies in other geographic regions and for other types of water bodies such as rivers are needed before we can be confident in generalizing this result.

Trout anglers' consumer surpluses are higher than non-trout anglers', but why? Trout enthusiasts might contend that trout are fun and challenging to catch and good to eat, however, anglers in our sample who did not target trout at all could express similar feelings toward their target species (bass, walleye, Koneke salmon…). Exploring some of the characteristics associated with the two types of anglers could help shed light on this. The following factors are suggested to be important: trip expenditure, diminishing return of recreation trips, angler attitudes / satisfaction, and group size.

Although trip expenditure alone do not constitute consumer surplus (it is the WTP above and beyond expenditure), but investigating the differences in spending between the two angler groups could reveal some of the underlying factors. Table 1.1 shows that non-trout anglers' per person gas cost were actually higher than trout anglers'. Hypothetically, if both types of anglers have the same maximum WTP, trout anglers would receive higher consumer surplus since they have spent less on trip expenditure (because net WTP is the amount above and beyond expenditures). On the other hand, the median total trip expenditures for both were about equal. Trout anglers also took fishing trips less frequently, since the median number of trips taken was two for trout, and four for non-trout anglers. This could lead to a diminishing return of recreation trip for the non-trout anglers. For instance, when the questionnaire asked anglers to value their most recent trip, it is more likely to be the trout anglers' first or second trip out that summer, but for the non-trout anglers, it could have been their fourth. This is especially helpful to explain why WTP is lower for non-trout anglers in the CVM result.

Figure 2 revealed that non-trout anglers felt that catching more and bigger fish were some of the more important aspects of their trip; while trout anglers valued peace and solitudes of their sites more, and they also enjoyed a wider range of secondary activities (hiking, scenery /wildlife viewing…) besides fishing. Therefore, it is possible that trout anglers in our samples were less likely to 'play down' the value of their trips due to a less than desirable fishing experience, since they also enjoyed other activities. On top of this, trout anglers did reported less perceived crowdedness, while non-anglers have a lower hourly catch rate.

Lastly, three other variables from Table 1 (*NUM_PARTY, SHARE_EXPENSE* and *PAYING_HOUSEHOLD*) revealed that non-trout anglers have fewer companions to travel and share trip / household expenses with. In happiness research, as well as in time-use research, it is known that the propensities to engage in activities depend on the availability of companions (Jenkins and Osberg 2005). Fewer travel companion also means fewer members to share expenses with, thus per person expenditure is higher.

These facts suggest that non-trout anglers would have taken fewer trips than trout anglers (which were not the case as shown in Table 1). However, an important counter-factor contributed to the fact that non-trout anglers actually took more trips is group size: the variable NUM_PARTY in the TCM models is negative and significant for both types of anglers. It is easy and intuitive to envisage that, a fishing trip would be more likely to materialized when planned alone or with one more partner, than having to plan a trip for three people / the whole family (median NUM_PARTY for trout anglers =3, while non-trout = 2).

1.5.1 Discussion and management implications

In this study we documented the process, and presented the resulting economic values of recreational angling for trout and non-trout anglers. These values can be useful in the resource management decision making process. As demand from recreational anglers increased steadily, the pressure and preference for stocking as a management strategy carries on across agencies. Ross (1997) lamented that wildlife management agencies today are managing a recreational activity, rather than conserving a wild resource. As mentioned in the introduction, the emphasis on stocking hatchery-reared trout has been well documented and even more prevalent in the western states such as Colorado. In fact, trout species accounted for 54% of total stocking by USFWS across the nation, more than any other species combined (Caudill 2005).

Naturally, there exists a need to justify such policy, both as an answer to anglers who pay most of the stocking costs, and to defend the current chosen management strategy. In the face of budget cuts and escalating spotlights on government spending, sound justifications are necessary for augmenting, or even maintaining, the level of funding for public hatcheries and various wildlife management agencies. In the process of assessing the benefits (and costs) of intensive trout stocking, some of the relevant questions include: (1) what are the economic impacts to local economies that are attributable to public hatcheries that focus heavily on trout species? (2) How do angler benefits received from trout fishing compare with other target species? (3) Can increasing the level and intensity of stocking improve the benefits angler receive? (4) Are there trade-offs associated with stocking mostly non-native species? For example, are there any ecological implications to consider?

The answer to the first question was reported in details in the background section of this paper. A great deal of efforts have been made to estimate the economic impacts (in terms of number of jobs, labor incomes and industry outputs) of trout fishing, in order to showcase the contributions to local economies from national fish hatcheries in the USA – which have been heavily focused on rearing rainbow trout (USFWS 2007; Harris 2010).

The results from our study also demonstrate a similar point, but by estimating the non-market economic value (in terms of angler benefits, or WTP) for recreational trout angling, as compared to anglers targeting other species. At the least, we have demonstrated that based on our sample in 2009, trout anglers' non-market benefits were about three times higher than non-trout anglers' regardless of which valuation method is used.

Since catch rate in the TCM models was not significant, we cannot make the assumption that the number of angler trip (and benefit) is influenced by catch. However, if catch rate is likely to enhanced by stocking, annual trout angler benefits would be higher than would have been the case without any stocking or decreased stocking. A detailed analysis on how much, or if, stocking affects angler catch rate, annual trips, and angler benefits would be valuable information to managers, and a meaningful topic of future studies.

It is worthwhile to mention the necessity to be cautions against over-simplifying the management decision making process by blindly using economic values. Besides showcasing the return to investments from stocking, another possible, and tempting management application from our results is when conflicts arise between managing for trout species versus non-trout species, economic benefits would favor emphasizing trout due to the higher benefits provided to anglers per day. Our data also support there are more trout anglers than other anglers at the reservoirs we sampled in Colorado. Although the angler benefits values presented here may help to inform tradeoffs between stocking trout and other fishery management objectives, needless to say, there are many other factors that must be considered in this type of decision. If emphasis is being placed on trout anglers, and stocking more trout in existing (or introducing into new) water bodies become the resultant policy, issues such as biota homogenization, inter / intra-specific competition, genetic integrity and biodiversity would reasonably be raised by ecologists, fishery scientists and others concerned with the ecological effect of stocking and species introduction (Halverson 2010; Rahel 2000, 2002). To sum up, while economic values provide essential information, nevertheless, it is only one element of sustainable fishery management. In particular, angler benefits constitute only one input into the decision rule when deciding on any sustainable resource management policy. A balance should be reached between ecological objectives and social objectives along with economic objectives.

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CHAPTER 2

AN ALTERNATIVE METHOD FOR ESTIMATING THE ECONOMIC VALUE OF STOCKED FISH

2.1 Introduction and Literature Review

2.1.1 Stocking hatchery-reared fish: a time-honored and widespread practice

Wildlife management agencies such as the U.S. Fish and Wildlife Service (USFWS) and various Departments of Wildlife / Fish and Game across the U.S have a strong tradition in stocking fish for recreational purpose. Right from its infancy, the U.S office of the Commissioner of Fish (forerunner of today's USFWS) treated raising hatchery fish as their primary mandate. Ross (1997) documented that 70% of the agency's budget ($295,000) in FY 1882 was for stocking efforts, largely because fishery managers 'knew how to raise fish better than they understood how to regulate harvest'. Enhancing a water body with hatchery reared fish has become a *de facto* tool for addressing issues from fishery declined, over-harvest, to satisfy recreation anglers' demand. In addition to fisheries managers' readily available skills in raising fish in hatcheries, the fact that other management tools such as setting harvest limit and regulations were understandably less popular, exacerbated the emphasis on stocking.

2.1.2 Evidence of favoring hatchery stocking programs

As demand from recreational anglers increased steadily, the bias on stocking carried on. Ross (1997) lamented that wildlife management agencies today are managing a recreational activity, rather than conserving a wild resource[1]. In 2004 alone, USFWS's

[1] In contrast, Colorado's Division of Wildlife, as directed by the Colorado General Assembly, has a duel mission to (1) manage and protect wildlife resources as well as to (2) provide recreational opportunities for the public (§33-1-101. C. R. S.).

top 11 hatcheries spent $5.4 million to rear 9.4 million rainbow trout across the U.S. (USFWS 2007). Similarly, state agencies across the U.S. (for 47 states that stock trout) stocked a combined total of 136.7 million trout in 1997 (Epifanio 2000). In 1995, Colorado stocked 15.9 million fish into its public waters (Epifanio and Nickum 1997); in 2008, the number increased five-fold to 79 million fish (CDOW 2009).

Not surprisingly, wildlife agencies' budgets have also been tilted toward hatcheries, or recreation related program. During FY 2005-2006, Colorado Division of Wildlife spent $98.9 million on four of their 'strategic areas': the top was $37 million on 'Wildlife Recreation', compared with $27.8 million on 'Responsive Management', $24.1 million on 'Wildlife Habitat and Species Management', and $10 million on 'Wildlife Education and Information' (CDOW 2006). Epifanio (2000) surveyed cold water fishery management agencies in all 50 states and found that overall, propagation accounted for the largest share of expenditure (as opposed to research, habitat, education, regulation and other). Some state's expenditure for propagation exceeded 50% of their entire fishery programs (Beside CO (57%) and NM (62%), these were all east-coast states: ME (60%), MA (58%), NH (78%), WV (75%)).

2.1.3 The need for valuing economic benefit of hatchery-stocked fish

It is clear from above paragraphs that public agencies have been partial toward stocking hatchery-reared fish in public waters in order to satisfy recreation angling demands. Naturally, the need for justifying such actions is imperative, both as an answer to tax payer, and to show cost effectiveness of program in order to sustain the agency's own future funding.

There is a rich body of literature on the economics of recreation angling. Johnston et al. (2006) have found over 450 non-market valuation studies that estimated anglers' WTP (Willingness to Pay) for their recreation experience and/or catching additional fish. But fewer studies have been devoted to estimating the value of stocked fish, more specifically, the economic value of an additional fish stocked. Reviews of the literature such as Johnston et al.'s (2006) uncovered the fact that recreation angler studies have mostly focused on estimating consumer surplus per angler day. Having a dollar value for a recreation day is important in and of itself, because it can account for the often undervalued (or ignored) nonmarket goods in terms of net economic benefit, such as recreational activities. This is of utmost importance for decision and policy makers alike.

However, having a dollar value in a per stocked fish is especially useful to policy analyses, because management decision is often made at the margin, so knowing the investment return from stocking one more fish is valuable and warranted. This study is focused on this task.

2.1.4 Information constraint for estimating the economic value of stocking

As stated above, recreation angler studies have mostly reported the value of an angler day. Calculating the dollar value per fish usually requires information on fishing pressure and effort, that is, the numbers of people fishing in a given body of water in a given period of time. Also required is information on the relationship between stocked fish and angler catch. That is, how many stocked fish released into the water would be caught eventually by anglers? But when such information is not available, simplifying assumptions were made.

For example, Johnson et al. (1995) examined the stocking efforts for two streams in Colorado, and found that the stocking of rainbow trout has not been economically efficient. In their calculations, a simplifying assumption about stock-catch relationship was made. They assumed that 60% of the trout stocked are caught by anglers and that the remainder died (therefore, they do not grow to the next age class and naturally, no reproduction). The authors' assumption suggests that for every trout an angler catches, 1/0.60 = 1.67 stocked trout is required.

It is not uncommon for researchers working on the economics of angling to face data constrain, especially data on fishing effort. Fishery, wildlife managers and agencies alike all face the problem of lacking comprehensive data (both biological population and human use data) to help guide management decisions. A review of Colorado's cold water fishery management by Epifanio and Nickum (1997) documented that comprehensive population inventory data (biological) are very limited for water bodies across CO. When that is coupled with decreased investment in creel survey, it makes senior biologists' (officials who actually make the decision on how many fish to stock in each water bodies in CO) task of assessing the impact of stocking very difficult. The decreased investment made for conducting creel survey (survey of fishing pressure, angler catch, etc.) is a point that should be stressed. Since creel surveys give the numbers of anglers fishing a specific water body at a given period of time, it is an important piece of data used for linking fish stocking to angler days, which in turn, is needed for estimating the dollar value per fish stocked. Bennett et al. (1996) reflected that too often researchers oversimplified the relationship between stocking rate and angler effort, or even satisfaction. They encapsulated the situation succinctly:

> "We do not have enough information to estimate demand accurately and, therefore, production ... Until the DOW has confidence in data describing anglers' demand and willingness to pay (by water category) ... we will not be able to manage our hatcheries proactively." (Bennett et al. 1996)

2.1.5 A review of existing approaches and literature

There are a few ways to calculate the net economic benefit of stocked fish, some less straightforward than others, but all require the linkage between the level of fish stocked to the change in angler benefits. This requires data on angler days, which depends upon the availability of creel survey, and as mentioned in the previous paragraph, is often not available. Alternative methods to obtaining this information are needed. Caudill (2005a) documented two main approaches to derive angler day estimates when creel data is not available and both involve using official fish stocking level (which is often readily available). The two approaches are: (1) the angler effort approach and (2) the angler visitation approach. The next two paragraphs briefly illustrate these approaches.

The angler effort approach requires three pieces of information: stocking data, angler catch rate, and effort. Stocking reports are often freely available to the public. Report such as the Colorado fish distribution schedule (CDOW 2009) contains a wealth of useful information, such as the location of stocking, species and number stocked, size (catchable vs. fry / fingerling), date of stocking and whether the stocked fish are whirling disease positive or negative. For example, Colorado DOW stocked 3,666,269 catchable fish in 2009 (CDOW 2009). Assume that 60% would be caught by anglers (the rest died or carried over to next year), and that on average, each angler catches 3.5 fish per recreation day. The total angler days equals to

$$Total\ angler\ days = \frac{Total\ fish\ stocked * Proportion\ of\ stocked\ fish\ caught}{Daily\ catch\ rate} \qquad \textbf{(2.1)}$$

In this hypothetical example, the total angler days = [(3,666,269 * .6) / 3.5] = 628,503. Multiplying this with the WTP for an angler day would give the net economic benefit from recreation angling in this fishery. Recalling the WTP value estimated from Chapter one (WTP = $191.6 per angler day), the net economic benefit in the study area is ($191.6 * 628,503) = $120,421,174. Assuming no other native species exist in the study area's water (that is, all catchable are stocked), the net economic benefit per stocked fish = net economic benefit in study area / total number of fish stocked. In this example, the net benefit per stocked fish is ($120,421,174/ 3,666,269) = $32.84. One major assumption in this approach is arbitrarily setting the proportion of stocked fish caught by anglers. The actual proportion would depend on a wide array of biological (mortality / survival rate, density dependence, fertility, etc.) and ecological (intra/inter-specific competition, trophic cascade, etc.) factors, and may be site dependent. On a related note, the catch rate may also varied by locations. Therefore, this approach is best suited for studying a single or small numbers of waterbodies where environmental and harvest conditions are very similar.

The angler visitation approach is aimed for estimating angler benefits across multiple sites / for a large system, such as a set of reservoirs supported by a hatchery system. This approach also depends upon the number of stocked fish in a given site. The difference is that it requires the actual number of angler days for <u>one of the site</u>. The idea is to construct a ratio of *stocked fish to angler days* for a given site, in order to apply to other sites without such data. Caudill (2005b) provides an example of this approach for a fish hatchery in Arizona. In this paragraph I give a similar illustration using some existing data for a stocked reservoir in western Colorado (Crawford State Park). There were 134,229 individual visits to Crawford State Park in 2009 (Schulz 2009, personal communication[2]), and since 18% of the visitor to a state park in Colorado participated in fishing (Corona Research 2008), we have 24,161 angler days in Crawford. There were 30,050 fish stocked at the reservoir (CDOW 2009). As with the angler effort approach described above, assuming that 60% of all stocked fish are eventually caught by anglers, the number of available fish at Crawford in 2009 would be 18,030. Therefore, the stocked fish to angler ratio is 0.74:1. Then, multiplying this ratio to the numbers of fish stocked to all other individual sites will result in the total angler days in the study area. It is clear

[2] Schulz, M. 2009. Colorado State Parks GIS specialist. Personal communication.

that this approach shares similar assumptions with the angler effort approach described above, but one additional heroic assumption, and the most critical, is that the site where the stocking ratio was calculated from is representative of all other sites in the study area. This often does not reflect reality.

In any case, efforts to estimate the benefit of stocking additional fish require establishing relationship between stocking levels and angler use. Angler use can be expressed in terms of visits, trips, days, or license sales. Very few studies have focused on the change in angler use in terms of license sales in response to stocking. Loomis and Fix (1998) analyzed two decades worth of fish stocking and fishing license sales data, and found that current season stocking of catchable trout was not a significant determinant of license sales. Stocking of warm water species did have a significant effect on license sales, however. They also found that the relationship between angler days and seasonal stocking was non-proportional: a 1% increase in stocking level resulted in only a 0.43% change in lake angler use. While fishing license sales is a standard and practical way to gauge angler use level, it is not as direct as using the number of trips, or visitation. Since license sales may or may not reflect actual use level, the reason is that a license holder might elect to fish daily during the fishing season, or just once. Others have placed their research focus on the relationship between catch rate and visitations. Studies in Idaho, Oregon, California, Montana and Colorado have found some correlations, albeit non-proportional, between increase in catch and visitation (Loomis 1992; Loomis and Cooper 1990; Duffield et al. 1987; Johnson and Walsh 1987).

2.1.6 Study objective

The objective of this study is to estimate the change in angler trips as a response to current season stocking level, in order to calculate the net marginal economic benefit per fish stocked for selected hatcheries-stocked reservoirs in Colorado. Besides the unique objective to derive a marginal fish value for stocked trout in Colorado's reservoirs, it also differs from existing studies in two ways. First, it does not rely on complete creel data that estimates the total number of anglers; second, it does not arbitrarily assume the proportion of stocked fish caught by anglers. As an alternative, this study aimed to estimate and utilize the relationships among catchable trout stocking level, angler catch rate, and visitations, in order to calculate the economic benefit of stocked fish.

2.2 Models, Method and Data

This section presents three models / equations that are used in conjunction to derive a marginal stocked fish value. It begins by first presenting a modified version of (1) the Travel Cost model (alone with willingness to pay results and parameter coefficients from the TCM model) already shown from chapter one. Then, (2) the Zero Inflated Poisson (ZIP) stock-catch model is introduced. This model establishes the relationship between stocking intensity and catch rate. Next, (3) a catch-trip equation is shown. This will be used to calculate the relationship between catch rate and annual fishing trips. Finally, using all of the above, the method for deriving a marginal value of stocked fish is presented.

This first sub-section below is restricted to the presentation of all models and equations, while the construction and explanations for different parameters are discussed in details in the data section.

2.2.1 Travel Cost Model

The Poisson travel cost model below (equation 2.2) differs from the one already estimated in chapter one in a minor way: the variable for catch rate is kept while the site substitution variable is taken out. A catch variable – *CATCHPERDAY* – is critical for this chapter since one of the objectives is to establish relationship between catch rate and annual trip[3].

$$\begin{aligned}(ANNUAL\ TRIP - 1) = \beta_0 + \beta_1\, PTOTAL\_GAS + \beta_2\, CATCHPERDAY \\ + \beta_3\, USE\_MOTOBOAT + \beta_4\, NUM\_PARTY \\ + \beta_5\, PAYING\_HOUSEHOLD + \beta_6\, EDUCATION + e. \qquad \textbf{(2.2)}\end{aligned}$$

Other than the change in two variables, this zero truncated endogenous stratification Poisson model is analogous to the one already estimated in chapter one. Trout anglers and non-trout angers are modeled separately.

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[3] The original TCM model in chapter one was not statistically significant when both the catch rate variable (*CATCHPERHOUR*) and the site substitution variable (*TRIP_OTHERSITES*) were added together, *CATCHERHOUR* was subsequently dropped.

2.2.2 Stock-catch model

In order to address the question of how an increase in stocking intensity changes angler catch, a Poisson process is used to model daily catch. Characterizing angler catch with a Poisson distribution is not a novel method, as the Poisson is well-suited for modeling non-negative response variable such as fish catch (McConnell et al. 1995; Morey et al. 2002). However, when there exists a disproportionately large numbers of zeros in the data (the dependent variable), the standard Poisson distribution no longer holds (Hilbe 2011). Relating to the issue of over-dispersion discussed in Chapter one, excess zero counts may also translate into a response variance that is greater than its mean, which violates the distributional assumptions of the Poisson process. The problem of fitting data containing excess zeros with the standard Poisson specification may cause the standard errors of the estimates to be deflated or underestimated, so that one or more predictor(s) in the model may appear to be statistically significant when it is actually not (Hilbe 2011).

A variant of the Poisson is the Zero-Inflated Poisson (ZIP) model, which allows overdispersion while taking into account of excess zeros in count data[4] (Lambert 1992). Referring back to the angler survey results presented in Chapter one, more than one-third of anglers caught zero fish during their trips. In order to model the daily catch rate – CATCH_PER_DAY – properly, a ZIP regression model is used. More specifically, the ZIP regression would model the catch rate for each angler via two different data

[4] ZIP models do this by increasing the conditional variance and the probability of zero counts in the Poisson process (Long and Freese 2006).

generation processes: (1) a zero-truncated Poisson process for anglers with positive catch as well as anglers with zero catch, and (2) a binary (Logit) process for only those with zero catch[5].

The ZIP stock-catch model (equation 2.3) assumes that the probability of anglers catching a certain number of fish (*CATCH_PER_DAY)* at a given site is a function of the fishing duration, target species, fishing skill, and stocking intensity at the site:

$$CATCH\_PER\_DAY = \beta_0 + \beta_1\, CBSTOCK\_ACRE50 + \beta_2\, SKILL + \beta_4\, FISH\_HOUR\_DAY + e \qquad \textbf{(2.3)}$$

Where, *CBSTOCK_ACRE50* is the proxy for fish density realized by stocking, it is expressed in terms of the number of catchable (10-12 inch long) fish stocked at a site per surface acre, in an increment of 50 fish. *SKILL* is the self-reported fishing skill level on a scale of one to ten. *FISH_HOUR_DAY* is the numbers of hours spent fishing per day. Trout anglers and non-trout anglers are modeled separately.

It is necessary to derive a marginal effect of stocking, because it is a required piece for the catch-trip model in the next section. For any linear regression, the parameter coefficients, β_k, are the slopes and marginal effects themselves; for semi-log regression, the marginal effects are simply e^{β_k} . For count models such as Poisson or Zero Inflated Poisson, however, the marginal effects of a parameter changes across observations. In

[5] To apply zero-inflated Poisson count models, there exist a number of pre-packaged commands in commercially available statistical software. For example, in STATA®, the zero inflated Poisson count model command is simply ‘ZIP’; while in SAS®, one can use the COUNTREG procedure with the ZEROMODEL statement.

order to correctly obtain the marginal effects at the mean from Poisson models, Hilbe (2011, p.126) derived the expression:

$$\frac{\partial E(y_i \mid \mathbf{X}_i)}{\partial X_{ik}} = E(y_i \mid \mathbf{X}_i)\beta_k = e^{X_i'\beta_k} * \beta_k \qquad \textbf{(2.4)}$$

The statistical software package STATA® has a standard post-estimation command – *margeff* – designed to calculate the marginal effects from Poisson models. The β_k is the parameter coefficient for interest (in this case *CBSTOCK_ACRE50*), and $\mathbf{X}`_i\beta_k$ is the linear predictors at the mean, which includes all other explanatory variables in the model. The marginal effect of an explanatory variable in a Poisson regression therefore depends not only on that variable itself, but also on all other estimated coefficients. The derived $\frac{\partial E(y_i \mid \mathbf{X}_i)}{\partial X_{ik}}$ is interpreted as the <u>factor</u> of change for every unit increase in *X* at predictors' sample mean. So, to arrive at the actual predicted catch given an increase in stocking, one would need to multiply that rate of change with mean catch:

$$\Delta\ CATCH\_PER\_DAY = (e^{X_i'\beta_k} * \beta_k) * \overline{CATCH\_PER\_DAY} \qquad \textbf{(2.4.1)}$$

Recall that one unit change in *CBSTOCK_ACRE50* equals 50 fish per acre; therefore, the *Δ CATCH_PER_DAY* is the change in catch rate resulting from stocking 50 more fish per surface acre.

2.2.3 The catch-trip equations

How does an increase in catch rate change the numbers of trip anglers go on annually? The TCM variables' sample means and the parameter coefficients from the Poisson travel cost model (2.2) are utilized to estimate the average numbers of annual trip based on current catch rate:

$$ANNUAL\_TRIP_{before} = \exp\{\beta_0 + (\beta_1 * \overline{PTOTAL\_GAS}) + (\beta_2 * \overline{CATCH\_PER\_DAY}) + (\beta_3 * \overline{USE\_MOTORBOAT}) + (\beta_4 * \overline{NUM\_PARTY}) + (\beta_5 * \overline{PAYING\_HOUSEHOLD}) + (\beta_6 * \overline{EDUCATION})\} \quad \textbf{(2.5)}$$

$ANNUAL\_TRIP_{before}$ signifies annual trip taken before the stocking intensity increase. This is essentially the predicted value of annual trip while holding all variables constant (at sample mean). But it can also be interpreted as the estimated numbers of annual trip based on current catch rate (before increase stocking). The following equation, however, estimate the number of annual trips due to an increase in daily catch as a result of increasing the stocking intensity:

$$ANNUAL\_TRIP_{after} = \exp\{\beta_0 + (\beta_1 * \overline{PTOTAL\_GAS}) + (\beta_2 * (\overline{CATCH\_PER\_DAY} + \Delta CATCH\_PER\_DAY)) + (\beta_3 * \overline{USE\_MOTORBOAT}) + (\beta_4 * \overline{NUM\_PARTY}) + (\beta_5 * \overline{PAYING\_HOUSEHOLD}) + (\beta_6 * \overline{EDUCATION})\} \quad \textbf{(2.6)}$$

$ANNUAL\_TRIP_{after}$ signifies annual trip taken before the stocking intensity increase. The number of annual trips due to an increase in daily catch as a result of increasing the stocking intensity is reflected in the term

$(\overline{CATCH\_PER\_DAY} + \Delta CATCH\_PER\_DAY)$. Where, the $\overline{CATCH\_PER\_DAY}$ term is the sample mean, which is the same as in equation 2.5; while the Δ *CATCH_PER_DAY* term is the result from 2.3.1, reflecting the level of increase due to an increase in stocking intensity. The entire equation 2.6 is essentially the fitted (predicted) numbers of annual trip given the increased daily catch rate as a result of stocking 50 more fish while holding everything else constant at sample means. Subtracting equation 2.5 from 2.6 yields the change in annual trip (*Δ ANNUAL_TRIP*) as a result of the increased daily catch from stocking 50 more fish per surface acre.

$$\Delta\ ANNUAL\_TRIP = ANNUAL\_TRIP_{after} - ANNUAL\_TRIP_{before} \qquad \textbf{(2.6.1)}$$

Once again, all equations shown above are done separately for trout and non-trout anglers. These calculation steps are organized and shown in Table 2.0 below.

2.2.4 Deriving the marginal value of stocking fish

First, using the sample mean for the number of days per trip (for trout and non-trout sample, respectively), *Δ ANNUAL_TRIP* is converted to the number of angler days:

$$\Delta\ ANGLER\_DAYS = \Delta\ ANNUAL\_TRIP * \overline{Days\_Per\_Trip} \qquad \textbf{(2.7)}$$

With the consumer surplus calculated from equation 2.2 here (*CS per angler day* = $1/\beta_{PTOTAL\_GAS}$), the change in consumer surplus is:

$$\Delta\ CS = \Delta\ ANGLER\_DAYS * CS\ per\ angler\ day \qquad \textbf{(2.8)}$$

This change in CS represents the increase in angler's willingness to pay, or net benefits, as the result of an increased in the number of trips taken due to additional catch rate, which was the result of stocking 50 more catchable fish per surface acre. Since the simulated level of increased stocking used was 50 catchable fish (*Δ Stocking Level*), the net benefit per fish is:

$$CS\ per\ fish\ stocked = \Delta\ CS\ /\ \Delta\ Stocking\ Level. \qquad \textbf{(2.9)}$$

All calculations shown above are performed for trout and non-trout samples respectively. All calculation steps are organized and shown in 7 steps in Table 2.0.

Table 2.0 Consumer surplus calculation per fish stocked

Calculation Step	Calculation / Equation Name	Equation #	Variables / Data used
1	CS per angler day	*2.2*	Modified TCM model from chapter 1
2	Δ CATCH_PER_DAY due to increased stocking	*2.4.1*	Sample mean for daily catch, with *STATA® command "Margins"*
3a	Predicted annual trips given current mean catch ($ANNUAL\_TRIP_{before}$)	*2.5*	Parameter coefficients and sample means from all variables in TCM model
3b	Predicted annual trips given increased catch ($ANNUAL\_TRIP_{after}$)	*2.6*	Parameter coefficients and sample means from all variables in TCM model, along with result from step 2
4	Δ Annual trip due to increased catch rate	*2.6.1*	Results from step 3a and 3b
5	Convert Δ Annual trip to Δ angler day	*2.7*	Result from step 4 and the sample mean of *DAYS_PER_TRIP*
6	Δ CS	*2.8*	Results from step 1 and 5
7	Value per fish stocked	*2.9*	Result from step 6 and stocking variable *CBSTOCK_ACRE50* (50 fish)

2.2.5 Data

Data for the travel cost model were obtained from the same angler survey presented in detailed in chapter one, therefore they will not be repeated here. As for the stock-catch catch model, with the exception of *CBSTOCK_ACRE50*, all of its variables were collected via the same angler survey instrument. The stocking variable – CBSTOCK_ACRE50 – represents catchable fish density realized by stocking at individual sampled reservoirs. It is calculated by dividing the number of catchable fish (10 to 12 inch long) stocked at each sampled site, by the surface acres for each water bodies. This is then divided by 50, so that one unit increase in this variable represents the required additional stocking that would result in 50 more fish per surface acre. Data were obtained through Colorado Division of Wildlife's fish distribution schedule (CDOW 2009).

Table 2.1 2009 stocking level for angler survey sampled sites

Sampled Reservoirs	Surface Acre	Species	Stocked Fish	Length (inch)
Blue Mesa	9,180	Rainbow trout	850,000	5
		Kokanee salmon	50,000	10
Crawford	414	Rainbow trout	10,000	12
		Catfish	5,000	8
		Largemouth bass	15,000	5
		Largemouth bass	50	19
Martin	200	Black crappie	50,000	1
		Catfish	8,725	8
		Greenback cutthroat	200	1
		Gizzard shad	200	10
		Largemouth bass	5,700	5
		Rainbow trout	24,000	10
		Sauger	25,000	1
		Wiper	5,000	1
		Walleye	20,000	1
Horseshoe	200	Black crappie	50,000	1
		Bluegill	10,000	2
		Catfish	8,000	8
		Gizzard shad	200	10
		Rainbow trout	24,000	10
		Sauger	50,000	1
		Tiger Muskie	1,600	7
Pueblo	5,399	Walleye	12,000,000	0.20
		Wiper	400,000	0.20
		Cutthroat - crossed	10,500	10
		Rainbow trout	10,500	10
		McConaughty rainbow	40,000	5
		Largemouth bass	10,000	5
		Flathead catfish	20,000	2
		Channel catfish	80,000	4
Ridgway	994	Rainbow trout	50,000	10
		Rainbow trout	15,000	12
		Brown trout	10,000	5
		Splake	10,000	3

Sampled Reservoirs	Surface Acre	Species	Stocked Fish	Length (inch)
		Rainbow trout	3,636	12
Harvey Gap	287	Bluegill	6,000	3
		Rainbow trout	19,000	10
Mesa Lakes	88	Rainbow trout	10,000	10
		Colorado river cutthroat	2,500	2
		Rainbow trout	8,000	10
		Colorado river cutthroat	2,500	2
		Rainbow trout	3,000	3
		Rainbow trout	5,000	10
Steamboat and Pearl lakes	1,011	Colorado river cutthroat	20,000	1
		Colorado river cutthroat	5,000	3
		Weminuche cutthroat	220	1
		Eagle lake rainbow	20,000	3
		Hofer x Harrison rainbow	120,000	3
		Snake river rainbow	30,000	5

SKILL is the self-reported fishing skill level on the scale of one to ten. Trout anglers on average reported 6.2 as their skill level; while non-trout anglers reported 7. *FISH_HOUR_DAY* is the number of hours spent fishing per day. For trout anglers, an average day of fishing took 4.07 hours, while non-trout anglers spend 4.79 hours. Lastly, the response variable *CATCH_PER_DAY* is the number of target species caught by anglers per fishing day. Trout anglers took 2.9 trout while non-trout anglers took 4.11 fish on an average fishing day. Even before diving into the regression results section, it is clear that from these summary data, trout anglers as a whole self-reported lower fishing skill, and spend less time fishing and caught less than non-trout anglers on an average fishing day.

2.3 Results

2.3.1 TCM regression result and WTP values

Other than a slight variables change, the zero truncated endogenous stratification Poisson travel cost model is analogous to the one already estimated in chapter one. Nevertheless it is necessary to present the new TCM regression results here (table 2.2), because any changes to the travel cost parameter coefficient (*PTOTAL_GAS*) will also alter the final consumer surplus calculation.

Table 2.2 Travel cost (TCM) truncated endogenous stratification Poisson (TESP) regression results by target species

Variable	Trout anglers	Non-trout anglers
PTOTAL_GAS	-0.001867	-0.003701
(standard error)	(0.0008)*	(0.000)**
CATCH_PER_DAY	0.028029	0.056824
	(0.007)**	(0.006)**
USE_MOTORBOAT	0.467503	0.463135
	(0.098)**	(0.143)**
NUM_PARTY	-0.081183	-0.056707
	(0.019)**	(0.018)**
PAYING_HOUSEHOLD	0.474921	-0.318329
	(0.062)**	(0.092)**
EDUCATION	-0.176146	0.000889
	(0.046)**	(0.04099)
CONSTANT	1.089693	1.801289
	(0.252)**	(0.297)**
N	135	93
McFadden's R2:	0.1249	0.1882
Z-Score	1929.2240	8.500E+08
Z-Score (p > |t|)	0.0730	0.3180
* significant at 5%; ** significant at 1%		

The Z-score values are not significant for either model, indicating that the hypothesis of no overdispersion cannot be rejected. The z-score in effect tests whether overdispersion exists and if negative binomial would fit the data better. The result confirms that as far as this data and the response variable are concerned, negative binomial regression is not superior to the standard Poisson specification (Hilbe 2011).

The only new component here is the catch rate – *CATCH_PER_DAY* – variable. Catch is positive and significant at 1% for both the trout and non-trout models. Following equations 2.4 and 2.4.1, if catch were to increase by one fish, annual trips would be expected to increase by 0.0909398 percent (trout) and 0.2810648 percent (non-trout) while holding all variables in the model at sample mean. Note that these values of marginal changes are for strict interpretation purpose only and are not used to calculate the marginal value of stocked fish in this study. The actual predicted responses to annual trips from a change in catch rate are derived in later paragraphs using equations 2.5 and 2.6.

To visualize how this change in catch rate correlates with annual trip, equation 2.5 is applied using the sample mean values in table 2.3 and simulated levels of catch (1 to 50).

Table 2.3 TCM model variables sample mean

Variable	Trout anglers	Non-trout anglers
PTOTAL_GAS	49.571	57.168
CATCHPERDAY	2.918	4.106
USE_MOTORBOAT	0.407	0.800
NUM_PARTY	4.358	4.084
PAYING_HOUSEHOLD	1.876	1.747
EDUCATION	4.321	4.022

Table 2.4 shows the simulation results while figure 2.1 graphically depicts the relationship by target species.

Table 2.4 TCM model variables sample mean

Simulated catch level (per day)	Predicted annual trip	
	Trout anglers	Non-trout anglers
0	2.62	3.15
1	2.70	3.24
2	2.77	3.33
3	2.85	3.42
4	2.93	3.52
5	3.02	3.62
10	3.47	4.17
15	3.99	4.79

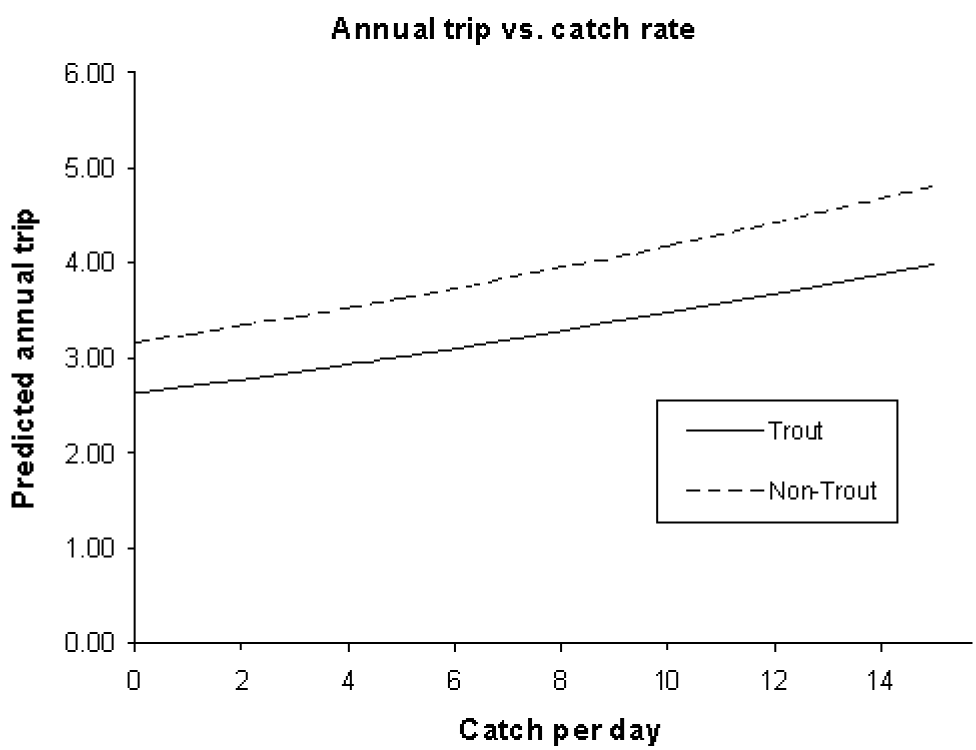

Figure 2.1 Relationship between simulated catch and predicted annual trip

As discussed in the data section, non-trout anglers took more fishing trips than trout anglers on average. What is also apparent here is non-trout anglers' rate of increase given an additional catch is greater than trout anglers'. The simulated catch level in table 2.4 stopped at 15 fish per day. Note that Colorado's state-wide possession limit ranged from 8 fish per day for rainbow, brown, brook, cutthroat, splake, golden and lake trout; 10 for brook trout, Kokanee, bass, catfish; 20 for Crappie and, unlimited for yellow perch, northern pike, whitefish, bullhead species (CDOW 2011).

The rest of the variables changed little in magnitude as compared with chapter one's TCM model, and all signs are unchanged. However small the parameter coefficient for the travel cost variable has changed, the willingness to pay values must be re-calculated. Applying equations 1.3 and 1.4, the willingness to pay per angler day for trout anglers is \$182.04 (90% CI: \$102.1 – \$838.8) and \$64.62 for non-trout anglers (90% CI: \$45.79 – \$109.75).

2.3.2 ZIP stock-catch regression results

The zero inflated Poisson stock-catch model regression results are shown in table 2.5. The Z-score test suggests that negative binomial regression is not superior to the standard Poisson specification, since real overdispersion does not exist for this dataset.

Table 2.5 Zero Inflated Poisson Stocking-Catch regressions results by target species

Variable	Trout anglers	Non-trout anglers
CBSTOCK_ACRE50	0.071953	0.338819
(standard error)	(0.0293)*	(0.051)**
SKILL	0.237303	0.104124
	(0.033)**	(0.031)**
FISH_HOUR_DAY	0.075019	0.073048
	(0.010)**	(0.008)**
CONSTANT	-0.690491	0.008213
	(0.253)**	(0.25798)
Inflated(CBSTOCK_ACRE50)	0.103628	0.515316
	(0.14208)	(0.2446)*
Inflated(CONSTANT)	-1.436920	-1.503150
	(0.338)**	(0.353)**
N	124	92
McFadden's R2:	0.0000	0.0000
Z-Score	222927.2	4298417.0
Z-Score (p > |t|)	0.2830	0.3180
Vuong test	4.3800	3.6400
Vuong test (p >z)	0.0001	0.0001
* significant at 5%; ** significant at 1%		

The Vuong score is to test whether the excessive zeros in the data is sufficient to warrant the use of ZIP model (instead of the regular Poisson specification). If the Vuong scores > 1.96, ZIP is a better specification for the data; V < 1.96 would suggests the regular Poisson is a better fit. For both trout and non-trout models, V > 1.96 with low p-values, which suggest that the zero inflated Poisson is preferred.

All parameters are positive and significant. Following equation 2.4, increasing stocking intensity by 50 fish per surface acres would increase the catch rate by a factor of 0.152 for trout anglers and 0.824 for non-trout anglers. For every additional self-reported fishing skill level, daily catch would increase 0.729 times for trout anglers, and 0.426 times for non-trout anglers. For every additional hour trout angler spent fishing, daily catch increase by a factor of 0.23, for non-trout anglers, it is a 0.29 fold increase. It appears that as far as catch rate is concerned, stocking intensity a more important factor for non-trout anglers.

The parameter *Inflated(CHSTOCK_ACRE50)* is generated with a binary process. Recall that the ZIP model is a special version of hurdle models, which are based on the assumption that zero counts and positive counts in the data are generated via two separate processes. The variables discussed so far are from a 'positive count' process, in the case of ZIP, anglers who actually have positive catch rate, as well as anglers with zero catch, are estimated using the zero-truncated Poisson process together with a binary processes[6]. Here, *Inflated(CHSTOCK_ACRE50)* is generated via a binary process (Logit), estimating the probability of being in the 'certain zero catch', or 'non-certain zero catch' group. The interpretation however, for ZIP models' binary portion differs from the traditional hurdle models. This is because the binary process in ZIP predicts the probability of success (1 or 0) in terms of whether the response has a zero count. A zero count response in ZIP's binary process is, in fact, a non-zero response or 'positive count'. Counter-intuitively, 'one' is actually a 'zero'. According to Hilbe (2011, p. 376), unfolding the relationship from ZIP models' binary component can be a source of confusion. But in the case of *Inflated(CBSTOCK_ACRE50)* here, the correct interpretation for its parameter coefficient

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[6] This differs from the traditional hurdle model, which separates the modeling of zeros from the modeling of counts, where only the binary process generates zeros. ZIP on the other hand incorporate zeros counts into both binary and count processes.

is for every unit increase in stocking, the odds of **not** being in the ‘certain zero’ catch group increases by a factor of exp(0.1036281) = 1.11 for trout anglers and exp(0.515316) =1.67 for non-trout anglers. This mechanical interpretation has an intuitive meaning: increasing stocking intensity **decreases** the chance of going home empty handed.

While these results are interesting, only *CBSTOCK_ACRE50*’s parameter coefficient is required for the marginal stocked fish benefit calculation. Following equation 2.4.1, the change in daily catch, *Δ CATCH_PER_DAY*, is 0.4426 for each additional unit increase (50 fish per surface acre) in stocking for trout anglers and 3.3838 for non-trout anglers.

2.3.3 Calculating a per stocked fish value

Using the TCM sample mean values in table 2.3, equation 2.5 is applied to arrive at the predicted annual trip given the current daily catch level; while equations 2.5 is applied, with the *Δ CATCH_PER_DAY* values calculated above, to arrive at the predicted annual trip given the increased daily catch level. Subtracting equation 2.5 from 2.6, the change in annual trip (*Δ ANNUAL_TRIP*) is 0.04 trip/year for trout anglers and 0.35 trip/year for non-trout anglers. Finally, equations 2.7 to 2.9 derived the change in CS as the result of an increased in annual trips due to additional catch, attributed to stocking 50 more fish: *CS per fish stocked* = $0.38 for trout and $1.88 for non-trout. Table 2.6 recapitulates the calculation steps as well as the results in this section.

Table 2.6 Consumer surplus per fish stocked calculations and results

Calculation Step	Calculation / Equation Name	Equations #	Results: Trout anglers	Results: Non-trout anglers
1	CS per angler day	*2.2*	\$182.03 per angler day	\$64.62 per angler day
2	*Δ CATCH_PER_DAY* due to increased stocking	*2.4.1*	0.443 fish/day	3.384 fish/day
3a	Predicted annual trips given current mean catch ($ANNUAL\_TRIP_{before}$)	*2.5*	2.84 trips/year	3.53 trips/year
3b	Predicted annual trips given increased catch ($ANNUAL\_TRIP_{after}$)	*2.6*	2.88 trips/year	3.88 trips/year
4	*Δ Annual trip* due to increased catch rate	*2.6.1*	0.036 trips/year	0.351 trips/year
5	Convert *Δ Annual trip* to *Δ angler day*	*2.7*	0.104 angler day	1.458 angler day
6	*Δ CS*	*2.8*	\$19.02	\$94.19
7	Value per fish stocked	*2.9*	\$0.38 per fish	\$1.88 per fish

2.4 Conclusion and Discussion

2.4.1 General Conclusion

Without relying on the often-lacked and expensive complete creel data that estimates the total number of anglers, this study derived the net economic benefit per fish stocked for selected hatcheries-stocked reservoirs in Colorado. By first modeling the relationship between stocking intensity and catch rate explicitly with a zero-inflated Poisson count model, this study did not arbitrarily assume the proportion of stocked fish caught by anglers. For both trout and non-trout anglers, there exist positive relationships between stocking intensity and catch rate, and, between catch rate and annual angling trips.

It is noteworthy that while the average consumer surplus per angler day for trout anglers exceeded non-trout anglers' by almost a factor of three (trout: $182.03/angler day; non-trout: $64.62/angler day), the final derived net economic value per stocked fish for non-trout is five times that of trout's (trout: $0.38/fish; non-trout: $1.88/fish). This disparity can be traced back to the average daily catch rate (trout: 2.918 fish/day; non-trout: 4.106 fish/day), as well as other summary statistics found in Table 1.1. On average, non-trout anglers took more trips on a year, spend more days on a trip and fished longer on an angler day. Coupled with higher catch rate, upon examining table 2.5, it is intuitive that non-trout anglers would respond to the increased stocking level with greater magnitude than non-trout anglers. This translates into the higher predicted annual trips from increased catch, hence non-trout's higher net benefit per fish stocked.

From stocking's stand point, the disparity between the marginal value of trout and non-trout is attributable to the relative amount of catchable stocked across water bodies. The amount of total catchable stocked for trout species is three times that of non-trout's (Table 2.1). Since there are more trout being stocked, hence at the margin there is a lower value of planting additional trout relative to non-trout (warm water species); conversely, since there are fewer non-trout species stocked, their marginal value is relatively higher.

Additional light is shed by referring back to chapter one's angler survey summary on angler perception regarding the important aspects of fishing trip. Recall that the angler survey asked respondents to rate the importance of a wide range of features of the water body they have visited (on a scale of not important, somewhat important, important, and very important). For trout anglers, experiencing 'peace and solitude', 'viewing scenery and wildlife' and 'fishing with family and friends' are the more important aspects of their fishing trip; on the other hand, non-trout anglers felt that 'catching large numbers of fish', 'catching trophy-sized fish' and 'fishing near skilled anglers' are comparatively more important. It is easy to comprehend that since non-trout anglers put more emphasis on the act of catching fish, they would be the ones sensitive to an increased stocking intensity.

2.4.2 Discussions and study limitations

It is necessary to remark upon some of the assumptions made in the construction of the stock-catch model (equation 2.3), especially *CBSTOCK_ACRE50,* which used stocking intensity as a proxy for fish density. It is reasonable that actual stocking numbers were not used because stocking 1,000 fish into Lake Erie is not the same as stocking 1,000 fish into a local reservoir. Table 2.1 revealed that the size of reservoirs ranged from 88 to over 9,000 surface acres, for this reason, the author feels that this density approach better reflects the fishing situations anglers faced. On a related note, the fish density / stocking variable assumed no carry over (fish stocked in previous year that survived into the next), nor considered some of the biological factors, such as natural mortality or cryptic mortality (proportion of catch-and-release returned into the water but died shortly after due to hooking, unhooking, exposure to air, play, stress, and other experiences while out of water). In sum, the static model used in this study inherently stated that the amount stocked = the amount available for anglers to catch (holding the other explanatory variables – skill and fishing hour – in the model constant). It would be a valuable exercise for future researches modeling stocking vs. catch rate to include some of the above biological and population dynamics characteristics the as explanatory variables.

Furthermore, *CBSTOCK_ACRE50* implicitly assumed that no fish exist in the water body until it is stocked by wildlife management agencies. This might not be the case if there are self-sustaining species (native or non-native) already in the body of water sampled. However, since the stock-catch model estimated the relationship between stocking and numbers of <u>target species caught</u>, for trout, it is true that none are native to the reservoirs sampled, so any trout caught must be attributed to the stocking efforts by Colorado Department of Wildlife. Furthermore, repeated annual stocking by the CDOW (exclusively increasing in the number of fish stocked annually) reflect these introduced non-native species have not yet reached the status of a self-sustaining population.

Therefore, the assumption for the trout angler model is valid in this regard. As for the non-trout model, this assumption should be relaxed somewhat, since there are a few species of self-sustaining species in selected reservoirs. The stocking variable *CBSTOCK_ACRE50* in a strict sense represented only a majority of the catchable anglers encounter on the trip, not all of it.

This study relied on survey data, therefore, its results reflects only those characteristics of the sample frame: anglers recreating on public reservoirs in Colorado during the summer months of 2009. It is not possible, nor the author's intend, to generalize the above consumer surplus results, for example, to claim that trout anglers in general have higher willingness to pay than other types of anglers; or that stocking non-trout species would results in a higher level of social welfare. Care must be taken in future recreational angling studies to take target species into account (if multiple species are present at the water body), since disparity exists among target species groups. Values obtained from studies that do not account for target species, by default, are 'average species' values, which may or may not reflect reality. Along the same line, benefit transfer method practitioners should also take this study as firm reminder that WTP varies across angler types / target species, even at almost identical locations (when policy site = study site). This is an important point to consider when collecting existing studies for building meta-analysis benefit transfer function.

The non-market recreational benefits of stocking as well as the economic impacts of angler visitations to local economies receive the bulk of the attentions from researchers. On the cost side, the administrative and resource inputs costs of stocking are often considered. However, this does not provide the complete picture of recreational fish stocking. There are ecological costs associated with the introduction / intensifying of stocking as well, especially for stocking non-native species. Consequences from the introduction of non-native fish include the disruption of wild population, altering algae production, declines in native fisheries and amphibian population, diseases and genetic problems (Knapp et al. 2001; Holmlund and Hammer 2004). Genetic problems have been caused by hatcheries' practice of using only a few males to fertilize all of the eggs. Whirling disease in trout is widespread, and has been exacerbated by poor hatchery practices. The disruption of wild population (via resource competition or direct predation) stemmed from either the intentional introduction of nonnative species, or from occasional escape (e.g. originally stocked at reservoirs, but ended up in Wild and Scenic River downstream that had no prior introduction). The direct effect from invasive species on native fishes and other aquatic biota had been vaguely touched upon in the literature. Pimentel et al. (2005) conservatively estimated that the economic losses due to exotic fish are $5.3 billion annually.

Accounting for ecological consequences from stocking is particularly imperative when value estimates like this study's are used as management or policy inputs, especially in states such as Colorado and Arizona (Horak 1995), where the provision of recreational fishing relied almost entirely on stocking non-native species. When agencies and hatcheries raise species that are only of particular interest to anglers, overtime, biota across regions will become more and more similar. Biotic homogenization in U.S. fish faunas has been documented by Rahel (2000, 2002), which reported that introduction of non-native fishes increased similarity of fish faunas in 48 states. This human selection of species and varieties narrow the diversity of the genetic stock (Hulata 2001). The current understandings of the economic value (loss) associated with decreased biodiversity is nebulous at best. In a study titled 'The economics of fish biodiversity', Tisdell (2009) *concluded* that economists currently have no concrete idea what the economic consequences of alterations in fish biodiversity are. He stressed, however, that aquaculture in support of production and recreation will likely to further reduce the biodiversity as well as genetic material diversity in the future, just as the way biodiversity of cultivated crops and domestic livestock have declined due to human selection of species and their varieties.

This dissertation chapter demonstrated only the method for estimating the marginal benefit of stocked fish in Colorado, an insightful and important future research direction would be to develop or strengthen current method of monetizing some of the abovementioned ecological cost.

While this study did not deal with the economic or ecological cost of stocking, it also did not account for <u>all</u> economic benefits from stocking. The marginal economic (non-market) value of stocked fish is by no means the 'total economic benefits'. Trip expenditures from anglers' visitations also have economic impacts. They affect local economies via direct spending and thereby creating jobs and income, triggering additional indirect and induced jobs and income. These economic impacts are equally important, in fact, as discussed in the introduction section, they have been the traditionally favored metric to showcase / justify recreationists' contributions to regional economies. The last chapter of this dissertation presents an example of deriving the economic impacts from another important resource originating from Colorado's public land: water.

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CHAPTER 3

ECONOMIC CONTRIBUTIONS OF WATER ORIGINATING FROM COLORADO'S NATIONAL FORESTS

3.1 Background and Introduction

3.1.1 National forests and water supply

Forest lands are critical to United States' water supply. Using state-of-the-art hydrological models and Geographic Information System, Brown et al. (2008) estimated that while only 29% of the continental United States' surface areas are forested, 52.68% of the water supply originates (surface water runoff via precipitations including snowmelts) on forested lands[7]. Out of those forested lands, 27% of which are part of the National Forest System, managed by the United States Forest Service. The Forest Service plays a disproportionately important role for water supply as well: while representing only 8% of the land area, National Forest Systems lands contribute 18.42% of the continental U.S. water supply in an average year.

Other than forested lands, the water supply in the U.S. also originates from rangeland (8.26%), agricultural lands (26.09%), wetland / fresh water bodies (7.72%) and other land cover types (5.26%). In terms of land ownerships, besides national forests, U.S.'s water supply also originates from Bureau of Land Management lands (1.47%), National Parks Service lands (2.07%), Bureau of Indian Affairs lands (0.91%), other federal agencies' lands (1.38%) and state and private lands (75.76%).

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[7] This contrast with the an estimate that has been routinely cited since the 1940s, which stated that up to 70 percent of the U.S's water supply comes from national forests (Gillian and Brown 1997). A special report on water by the U.S. Forest Service pointed out that this claim was overstated and lacks a clear empirical basis (Sedell 2000). Brown et al.'s (2008) modeling effort is likely the most accurate estimates of overall U.S. water supply available to date. All numbers and percentages reported in this section were calculated using data found in the Appendix in Brown et al. (2008).

While most of the U.S.'s water supply comes from state and private lands as a whole, however, this picture changes dramatically when looking at specific regions of the country. For some states, more than half of their water supply comes from national forests, namely Utah (69.47%), Colorado (68.19%), Idaho (67.75%), Montana (61.3%), Arizona (53.45%) and Wyoming (53.1%). It is clear that national forests play an unduly important role for the water supply in the western U.S.

The concept of water supply deals mostly with quantity. But water quality and timing of water availability are two equally important issues surrounding water resources management. Quality water in predictable quantity is one of the major ecosystem benefit provided by intact forest ecosystems.

People have been appreciating this fact long before the age of ecosystem research, advance modeling and GIS applications. In fact, the present-day Forest Service was created over 120 years ago with water in mind. The Organic Administration Act[8] of 1897 states that (emphasis added):

> "No national forest shall be established, except to improve and protect the forest within the boundaries, or *for the purpose of securing favorable conditions of water flows*, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States…"

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[8] It is worth pointing out that the Organic Act of 1897 (16 U.S.C. §§ 473-478, 479-482 & 551) did not created the present-day national forest systems, rather, it provided management direction and authority to existing forest reserves, which were already established through the Forest Reserve Act of 1891 (16 U.S.C. §§ 471). It was not until 1905 that the forest reserves were transferred from the Department of Interior to the Department of Agriculture and were renamed 'national forests'.

Five years after the passage of the Organic Administration Act, the Forest Reserve Manual[9] (DOI 1902) explicitly stated that there were only two 'object of the forest reserves', they are:

> "(1) To furnish timber a valuable and much needed product, from lands which are unfit to produce a more valuable crop, such as corn or wheat. (2) To regulate the flow of the water. This they do *(a)* by shading the ground and snow and affording protection against the melting and drying action of the sun. *(b)* by acting as wind-break, and thus protecting the ground and snow against the drying action of the wind. *(c)* by protecting the earth from washing away, and thus maintaining a 'storage layer', into which rain and snow water soak and are stored for the dry seasons, when snow and rain are wanting. *(d)* by keeping the soil more pervious, so that water soaks in more readily and more of it is thereby prevented from running off in time of rain or when the snow is melting"

Unmistakably, water issue was at the forefront during Forest Service's infancy, as this detailed description of the benefits of forests to water flow appeared on the first page of the forest manual. Besides some jargon changes (i.e. ecosystem services), these one century-old descriptions of benefits of forest for water flow remain accurate today (Furniss et al. 2010). Nevertheless, only during the past decades have the Forest Service began to refocus the agency on its original mission (Sedell 2000).

[9] The manual was the first U.S. forest reserves officials' guide book. It contained general information about forest reserves as well as practical topics regarding official duties and standing of forest officers, restrictions and penalties, sale of timber in the reserves, free use of timber and stones, etc.

3.1.2 Study motivations and importance of water benefits valuation

The Forest Service manages a diverse resource base. The Multiple Use – Sustained Yield Act of 1960, as amended in 1996 by P.L.104-333, directs the U.S. Forest Service to manage for timber, outdoor recreation, range, watershed and wildlife and fish purposes (P.L. 86-517; 16 U.S.C. §§ 528-531). There are public benefits associated with activities conducted by the Forest Service as an agency, as well as from the use or enjoyment of managed resources by local communities. National forests contribute to the local economy mainly in terms of jobs, income and outputs. For example, when timber is sold and cut from the forest, impacts occur throughout different sectors in the local economy (from logging, transportation, to wood manufacturing industries). In the process, sales, outputs, jobs and income are generated, while additional income received by workers in these sectors contributes to additional spending by households (induced effects). Similar scenarios take place when mineral extraction, grazing, recreation (from visitor spending), and fuel reduction clearing activities occur on national forests. Local communities also benefit from Forest Service employment salaries, agency expenditures in the area economy as well as county payments (such as the Payment in Lieu of Taxes (PILT) program and funding from the Secure Rural Schools and Community Self-Determination Act (SRS)). Other benefits exists as well, such as non-market values of recreation, non-use values of an intact forest ecosystem, economic impacts of water supply to local economy, and other benefits from ecosystem goods and services in a forest setting.

Regulatory and statutory requirements are the primary motivations behind this study's attempt to estimate economic impacts of water supply originating from Forest Service lands. Under the Multiple – Use Sustained Yield Act of 1960 (P.L. 86-517; 16 U.S.C. §§ 528-531) and the National Environmental Policy Act of 1969 (83 Stat. 852; 42 USC 4321, 4331-4335, 4341-4347), the Forest Service is obligated to conduct economic impacts analysis as part of the forest planning process. The 1982 National Forest System Land and Resource Management Planning Rule[10] (39 CRR Sec. 219.12g(3)) specifically required that economic effects be examined for each management alternatives the Forest Service carries out, furthermore, §219.23a explicitly called for estimating current water uses, both consumptive and non-consumptive, within the area of land covered by the forest plan.

Economists within the Forest Service are charged with the responsibility to perform economic impact analysis on activities and programs of, as well as resources managed by the Forest Service. Periodic economic impact analyses have been performed in order to showcase the impacts in terms of outputs, jobs, and income from selected management activities. These include timber harvest, grazing activities, recreation visits, county payments, agency salaries and expenditures. Water supply – an important natural resource that could be affected by agency management decisions – however, have not

[10] The National Forest System Land and Resource Management Planning Rule (also known simply as The Planning Rule) is the primary document that guides all natural resource management activities by the U.S. Forest Service. The 1982 version remained the valid version, and is abided by the agency as of the submission date of this dissertation. This is because all updated versions (2000, 2005 and 2008) of this rule have been either overturned in Federal courts and / or reverted back to the previous version.

been included as part of the periodic economic impact analysis efforts[11]. The inherent natures of water explain some of the reasons behind this lack of focus on water, more detailed discussion are found in the next paragraphs.

In addition to statutory and regulatory requirements, the needs for measuring economic benefits of water originating from national forests are further motivated by: (1) the current lack of reliable price information for water, (2) and rising water demand and scarcity in the western U.S due to population growth and climate change. The next few paragraphs describe these two points at length.

Economic measurements such as benefits and impacts in dollar terms are vital information for decision making. When making natural resource management decision, information on the economic benefits of resources such as water – arguably the most important of all resources – are especially useful but are often missing or inadequate. However, it is frequently the case that water is under-priced and under-valued, or not valued all together in some instances (Brauman et al. 2007; Emergon and Bos 2004). The longstanding ‘diamond-water paradox’ is an exemplification. Properties such as externality, natural monopoly and public goods (non-rival and nonexclusive) have distinguished water from other goods and commodities that have market-clearing prices. Furthermore, legal institutions relating to water are diverse and region-specific, which

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[11] There have been efforts to derive national forests’ economic values for water (Brown 1990, 1999 and 2004). These reports are tremendously valuable, but were conducted in a research capacity and not as operational analysis and / or as part of a forest planning process. As explained in the literature review section below, economic values and economic impacts are different concepts. This dissertation however, focuses on economic impacts.

further complicates the economics of water[12]. It is clear that the 'market price' of water – if available – is neither an appropriate nor a reliable metric for communicating the value of this important resource (Glennon 2009; Saliba and Bush 1987).

In light of the above, a good deal of research has been aimed at monetizing the benefits of water to various types of uses (see literature review section below), because having reliable economic value gives powerful signal to different users, as well as provide necessary decision inputs to resource management. At a United Nations meeting on water and the environment, the famous Dublin Statement declared:

> "Water has an economic value in all its competing uses and should be recognized as an economic good…Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources." (The Dublin Statement, United Nations 1992)

In a forest setting, the marginal (e.g. $/unit water) and total values of water originating from an area provides meaningful information. Knowing the marginal value of water can answer the question of 'what is the value of a change in water flow to the public supply, due to forest management actions such as road constructions and timber

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[12] Numerous water laws exist, for example: the riparian doctrine (common property in surface water), the eastern permit systems (state property in surface water), the prior appropriations doctrine (private property in surface water), the correlative share system (private property in surface water), the absolute ownership system (weak common property in ground water), the reasonable use law and the correlative rights system (common property in ground water), and the Vernon Smith system (advanced private property in ground water). While the descriptions and explanations of each of these institutional frameworks are outside the scoop of this chapter, see Griffin (2006) for a full review.

harvest?' As for the total value of water, Brown (2004) pointed out that there is "no plausible land management decision that is enlightened by an estimate of the total value of water leaving a forest area." Nonetheless, if there is a need for comparing the relative importance of different – sometimes competing – resource users on public lands, estimating the total value of water would be useful. For example, land managers could compare the total value of water originating from a forest, with the value of other exploitable resources in the same area such as timber harvest, road construction, recreation, livestock grazing, etc. The total value of water can be a valuable measure for natural resources management decision makers in agencies with a multiple-use objective such as the U.S. Forest Service. In this paper, both the marginal and total benefits of water originating from national forests are estimated.

The continuously rising population, and therefore demand, for water in the western states calls for more intensive and efficient management strategy. For example, Doyle and Gardner (2010) projected that if Colorado's population doubles in the next 20 years, the demand for water will exceed supply by 630,000 acre-feet. Besides the population driven demand rise, the prospect of water scarcity in the west is further augmented through a possible change (decrease) in the supply side, largely driven by climate change. Regardless of the debate on anthropogenic climate change, state-of-the-art climate models predict overall that most of the western U.S. will become hotter and drier as a result of climate change (Diffenbaugh et al. 2008; Bates et al. 2008; Hall et al. 2008; IPCC 2001). It is intuitive to understand, even to non-scientists, how the drier condition would decrease the flow of water supply through the reduction in rainfall. The hotter climate condition, however, not only shrink the natural flow of water supply via increased evapotranspiration and soil moisture loss, it also perpetuates the problem of rising water demand. Because a hotter climate not only increases consumption of drinking water (which is a minuscule amount of water withdraws compared to other water use, see Data section for more on U.S. water use statistics), more importantly, it also increases the demand for irrigation and electricity[13] (air conditioning, refrigeration...). It is evident that the rising demand for, and decreasing supply of water jointly escalate the issue of water scarcity in the western U.S.

All factors discussed hitherto point to the necessity of better water resources management, or land management actions that would directly / indirectly affect water supply, which require reliable economic information based on best available science. The next section gives a concise review on existing method for estimating the economic benefits (in terms of economic impacts) of water.

3.1.3 A review of frameworks and methods

3.1.3.1 Framework for valuing water use

Economic benefits from water supply can generally be expressed in terms of (1) economic impacts (i.e. jobs, incomes, retail sales supported by water as an input) and / or (2) 'net economic benefits' (i.e. willingness to pay for quality water in predictable

[13] According to the U.S. Geological Survey (USGS), 49% of all water use in the U.S was for thermoelectric power generation, constituting the largest use category (Kenny et al. 2009). Details on water use statistics are found in the Data section below.

quantity). Since this study focuses on the economic impacts of water, only literatures and methods pertaining to this area are presented in details.

Various frameworks and methods have been developed to address the use-value as well as non-use value of water. Non-use values measure people's willingness to pay for the water without directly or physically consuming it. These include existence (the enjoyment one gets just from knowing that a desirable quality or quantity of water exists), option (the ability to consume a desirable quality or quantity of water in the future) and bequest (knowing the possibility that the future generation will be able to consume and enjoy the water) value of water. Some recreation such as canoeing relies on a desirable amount of stream flow, water in this case supports the recreation activity thus it is a type of non-consumptive use. These non-consumptive uses, existence, option and bequest values, as well as other environmental public goods values of water can be monetized using non-market valuation techniques such as contingent valuation, travel cost, and hedonic property methods and are outside the scoop of this chapter.

As for valuing the consumptive use of water, one could either measure the benefits of water as final goods or as intermediate goods. Valuing water as final goods requires analyst to view water through consumers' lenses. Residential water use is the most familiar of all uses of water as final goods, and has received the bulk of the attentions from economists (Young 2005; Griffin 2006). Econometrically estimating residential demand function is the most common method for valuing this residential water use. Howe and Linaweaver (1967) were the first to do to this by estimating the relationship between the price of delivered water and residential use level by indoor (drinking, cooking, bathrooms) and outdoor use (grass lawns, flowerbeds, car washing) categories. They have found that the indoor water use demand was more price-inelastic than outdoor water use demand. Numerous residential water demand analysis have been carried out since then, Dalhuisen et al. (2003) synthesized four decades of residential water demand studies (64 individual studies in total) and found that price elasticity ranged from -7.47 to +7.9. Griffin (2006) criticized that this extreme range of elasticity is both 'hard to comprehend' and 'unacceptable', given some of the collected studies contained poor quality data and / or statistical issues. Young (2005) explained some of the specific issues in econometrically measured residential water demand function. For instance, there is little variation in price (delivered residential water price from one monopolistic supplier), and reasonably accurate data from metered deliveries are often not available. Furthermore, if block rate structure exists, the endogenous price will change according to use level, therefore, some of the linear econometric models used will produce biased results. From these demand functions, analysts are able to derive the economic value for residential water use (Young and Gray 1972; Griffin 1990).

Besides residential water demand analysis, similar method has been applied to irrigated crop water. A meta-regression analysis by Scheierling, Loomis and Young (2006) found that irrigation water price has a positive and significant effect on price elasticity estimates. However, the presence of high-value crops does not affect water price elasticity, due to the relatively low water prices in the study areas. This result echoes the earlier discussion regarding the issue of reliable price information on water resources. Nevertheless, the authors concluded that method of analysis has a significant impact on price elasticity estimate on irrigated water.

Considering water as intermediate goods is a framework often used for valuing the economic impacts of water supply. By looking at water through producers' lenses, this framework aims to measures the economic impacts, usually in terms of total output, that are attributable to water as a resource input during the production process. It is routinely applied to the irrigated crop sectors.

3.1.3.2 Input-output approach: Agricultural sectors

Thorvaldson and Pritchett (2006) estimated the economic effects of a reduction in irrigated acreage on four regional economies in Colorado using Input-Output (I-O) models. The authors employed a 'with-and-without' approach – what would happen when all irrigated crop production have to be converted to dry crop due to lack of water – to impute the economic impacts water have on the economy. Depending on the region, total economic impacts from irrigated crop sectors (or the loss thereof) ranged from $13.55 (2002 USD) to $110.07 million, while the total number of jobs lost ranged from 187 to 1,086. Howitt et al. (2009) investigated the economic impacts of water reduction for the agriculture sectors in the Sacramento, San Joaquin and Tulare regions in central California. They used an I-O model to project that a drought condition translates to a loss of $586 million (2008 USD) in agricultural sectors revenue and 16,000 jobs. The depleting Ogallala Aquifer has been receiving much attention from environmentalists and economists alike. Guerrero et al. (2010) projected with an I-O model that if all irrigated cropland are converted to dryland farming due to a depleted Ogallala Aquifer, it would cause a loss of $1.24 billion in industry output, $474 million in value added and 12,113 jobs for the Texas panhandle region. Golden and Leatherman (2011) also used an I-O model to estimate the economic effects of irrigated cropland water reduction in central Kansas' Wet Walnut Creek area. They projected that the decrease in irrigated crop acreage would result in the loss of $4.5 million (1992 USD) in total output, $2.8 million in total value added and 59 jobs in the local economy.

Many irrigated agricultural water impact studies take on the assumption that when faced with severe water reduction or long term drought conditions, producers react by changing their production from the irrigated varieties to dry crop farming. Nevertheless, this may or may not be the case. Since not all producers would responded in the same manner, in reality, geographical and financial variables all factor into their decision making. Amosson et al. (2009) accounted for this in their I-O model for the Ogallala Aquifer region. By converting only 10% of the irrigated crop acres in the region over 15 years, they found that this switch decreased the overall regional economic activities by only 1% compared with the baseline.

Although the intermediate goods framework is routinely applied for the irrigated crop sectors, it is also possible to use it to derive the economic contribution of water to industrial and commercial sectors, albeit they have received less attention from economists in general (Young 2005). This is due to the relatively small proportion of water use / input cost for many industrial and commercial sectors. There are exceptions, for instances hydropower production (Harpman 1999) and waterborne transportation

(Howe et al. 1969). There are also ample studies regarding water based recreation economics, which non-market studies constitute the bulk of its literature and are outside the scoop of this paper. To the extent of economic impacts of water from recreation visits, Berrens et al. (2006) made the connection that New Mexico's Inventory Roadless Area (IRA) are important to the desired quality and quantity of water flow, which provides opportunities for many recreational activities, thus sustaining sectors that support those activities. Using Loomis and Richardson's (2000) I-O recreation multiplier, Berrens et al. (2006) have estimated that for each acre of IRA, 0.000568 jobs and $13.84 worth of personal income are supported by these roadless recreation activities.

3.1.3.3 Input-output approach: Value-added

The value-added method is used to derive water's economic impacts in any given sector where water is an intermediate good. One can estimate the impact of water as an input to production, sector by sector, via an input-output model of a given regional economy.

In the value-added approach, the imputed value of water is calculated by dividing the gross regional income (or value added and other measures of economic performance) from a sector, by the amount of water used by that sector (Lichty and Anderson 1985). The result is in dollar per unit of water, which is useful in management settings. Detail on the method is found in the data and method section. Moncur (1974) used a state-wide regional input-output model to calculate the value added per unit water use for the state of Hawaii. He estimated water values for 54 sectors in Hawaii, and they ranged from $0.098 per million gallons for some agricultural sectors, to $309.2 per million gallons for the printing and publishing sector. Wollman et al. (1962) used New Mexico's 1954 gross regional (state) product and evaluated the contribution of water from the Rio Grande basin. They reported that the value added of water to the state economy was \$44 to \$51 (2011 USD = \$369 to \$428) for each acre-foot of water used in agriculture; \$212 to \$307 (2011 USD = \$1,779 to \$2,576) for each acre-foot used as fish and wildlife habitat, and \$3,040 to \$3,989 (2011 USD = \$25,509 to \$33,472) for each acre-foot used in industrial sectors. An I-O analysis had been conducted for Humboldt and Lander counties in Nevada to derive water's shadow price among nine aggregated sectors (Harris and Rea 1984). The authors found the values of water (\$ output per acre-foot) varied greatly depending upon simulated water availability, however in general, the agricultural sectors did not response to the increase of water availability in such great magnitude as other sectors (i.e. manufacturing, services, etc.). Based on the value-added concept, Bouhia (2001) modeled Morocco's economy with a 1995 input-output table and estimated the shadow price of water for 14 agricultural sectors and two aggregated industrial sectors. Results ranged from 2.36 Dirhams per m^3 of water use for sugar cane, to 92.01 Dirhams per m^3 for the industry/services sectors (1 US dollar = 7.8995 Moroccan Dirhams).

There exist different adaptations to the value-added method. Omezzine et al. (1998) applied a variation of the value added method to estimate the economic returns to water from surface irrigation in Oman. Total value products of different crop are divided by the physical amount of irrigated water for that crop. The resultant average economic returns to water ranged from 0.082 Rial Omani (1 US dollar = 0.38 OMR) per cubic meter for banana to 0.422 Rial Omani per cubic meter for potatoes. In Texas, a study by the South Central Texas Regional Water Planning Group (SCTRWPG 2001) used 1995 IMPLAN® data and calculated 'water use coefficients' for four different water user groups in Texas's panhandle. The water use coefficients are average dollar value of output sold to final demand per acre-foot of water used in four aggregated sectors: steam electric ($6,501/acre-foot), mining ($5,786 /acre-foot), irrigation ($121 /acre-foot) and livestock ($13,356 /acre-foot). In a California study, Gleick (2004) used employment and water use statistics and calculated the number of jobs and output per unit water used, and described them as the 'economic productivities of water'. The author found on average one thousand acre-feet of water support 22,000 jobs in California's industrial sector, 6,600 jobs in the commercial sector, and 12 jobs in the agricultural sector. In terms of output, an acre-foot of water contributed to $575,000 worth of Gross State Product (GSP) in California's industrial sector, $545,000 in the commercial sector, and $900 in the agricultural sector. It is worth noting the disparity of economic productive of water among sectors. In Colorado, Adams et al. (2009) used 2007 IMPLAN® data to derive the ratio of total regional sales and total regional water withdrawals for sectors in five regions (Western Colorado, San Luis, Central, Front Range and Eastern Colorado). The resultant 'water productivities' are literally economic activity per acre foot of water. The authors found the total sales per acre foot of water used for the Front Range region in 2007 was $132,268, highest of all five regions. The second place, in contrast, was Central Colorado, at $12,326 per acre foot. Although different variations to the value-added method abounds and different names given to the value estimated , the end results always consisted of the ratio of some economic performance measurement and unit water used.

Table 3.0 summarized the above studies. Note that the fifth column presents results from individual studies in 2011 US$. However, values per volume water use (Mgal vs. Acre-ft) are left in the units found in individual studies. Since each study reported only the value per unit water used – which is a quotient of volume and $ value – therefore, without knowing the actual volume of water employed in the calculation, it is mathematically incorrect to simply use a conversion factor to convert results to a standard unit (i.e. $/acre-ft).

Table 3.0 Past value-added input-output studies results summary

References	Location	Commodities (selected) Valued	Result / units: Benefit per unit water as reported	2011 US$	Value measured
(Wollman et al. 1962)	New Mexico	Agricultural sectors	212-307 US/Acre-ft	1,799 - 2,576 US/Acre-ft	Value-added
		Industrial sectors	3,040 - 3,989 US/Acre-ft	25,509 - 33,472 US/Acre-ft	Value-added
(Moncur 1974)	Hawaii	Agricultural sectors	0.098 US/Mgal	0.45 US/Mgal	Value-added
		Printing and publishing sectors	309.2 US/Mgal	1420.85 US/Mgal	Value-added
(Omezzine et al. 1998)	Oman	Banana	0.082 Rial Omani/m^3	0.29 US/m^3	Total value product
		Potato	0.422 Rial Omani/m^3	1.53 US/m^3	Total value product
(Bouhia 2001)	Morocco	Sugar cane	2.36 Dirhams/m^3	0.43 US/m^3	Value-added
		industrial / services sectors	92.01 Dirhams/m^3	16.86 US/m^3	Value-added
(SCTRWPG 2001)	Texas	Steam electric	6,501 US/Acre-ft	8,994.91 US/Acre-ft	Total value product
		mining	5,786 US/Acre-ft	8,600.98 US/Acre-ft	Total value product
		irrigation	121 US/Acre-ft	179.87 US/Acre-ft	Total value product
		livestock	13,356 US/Acre-ft	19,853.9 US/Acre-ft	Total value product
(Gleick 2004)	California	industrial sectors	22,000 /thousand acre-ft		Jobs
			575,000 US/Acre-ft	735,535.71 US/Acre-ft	Total value product
		commercial sectors	6,600 /thousand acre-ft		Jobs
			545,000 US/Acre-ft	697,159.94 US/Acre-ft	Total value product
		agricultural sectors	12/thousand acre-ft		Jobs
			900 US/Acre-ft	1,151.27 US/Acre-ft	Total value product
(Adams et al. 2009)	Colorado	All sectors (Front Range region)	132,268 US/Acre foot	144,518 US/Acre foot	Total value product
		All sectors (central Colorado region)	12,326 US/Acre foot	13,467 US/Acre foot	Total value product

3.1.3.4 Other approaches

Some researchers have attempted to elicit economic values from water market transaction data (Hartman and Seastone 1970). A recent example is Brown's (2004) work at the U.S. Forest Service. Although it was explicitly stated that the study pertains to the economic values of water, not impacts, it is nevertheless relevant here because it is the most recent attempt to derive the marginal economic value of run offs from national forests in the continental United States. A total of 1,726 individual water transactions (both water rights transfers and water leases) from 1990-2003 in the western U.S. were analyzed. It was shown that the average price of water transaction was $96 (2003 USD) per acre-foot per year. Across the western states, that price ranged from $15/acre-foot in Idaho to $246/acre-foot in Oklahoma. In terms of water user types, irrigation ($46/acre-foot) and recreation ($44/acre-foot) related transactions have the lowest average price while mining ($409/acre-foot) had the highest values. Finally, accounting for geographical variations in transaction prices, the total value of runoffs from national forest in the continental United States was estimated to be $7.2 billion per year (Brown 2004).

3.1.4 Study objective

National forests contribute a substantial portion of water to the public supply in western states. In particular, units in the national forest system in Colorado are estimated to provide 68% of the water supply originating within the boarder of Colorado in an average year (Brown et al. 2008). Following the motivations offered in 3.1.2, this chapter aims to employ a customized version of the value-added approach, using a regional input-output model to derive the marginal economic contributions to each economic sector in the state of Colorado. Using Colorado as a case study, this chapter will demonstrate a method of calculating the economic contributions attributable to water originating from Colorado’s national forests.

3.2 Data[14]

3.2.1 Water withdrawal data

Since 1950, the United States Geological Survey (USGS) collects and publishes estimates of water withdrawals every five years[15]. Data are reported by water use categories at the national, states and counties levels. As a nation, the estimated water withdrawals in 2005 was 410 billion gallons per day (includes both surface and ground water, also accounting for both fresh and saline water). Out of which, 49% were used for thermoelectric power generation – the top use category in the U.S. (Kenny et al. 2009)[16]. The second highest water use category was irrigation (31%), followed by total public supply (11%), industrial use (4%), aquaculture (2%), mining (1%), domestic households (1%) and livestock (1%). At state levels, these distributions varied. In Colorado, total water withdrawals for the entire state in 2005 were 13.627 billion gallons per day, or 4.974 trillion gallons per year. The top water use category was irrigation (90%) while thermoelectric power generation – the number one use of water at the national level – accounted for less than 1% of the total withdrawals in Colorado. Table 3.1 shows the total water withdrawals and the percentage of total withdrawals by water-use category in

[14] Unlike the previous two chapters, here I introduce the data before presenting the method section, because the calculations in this study are data driven, where the approach used are driven by the availability of secondary data sources.
[15] The 2005 water use data is the most, which was released on October 27th 2009; the 2010 water use data are projected to become available to the public at the end of 2014.
[16] While this is the official citation for the 2005 USGS water use report, all data tables and summary statistics regarding water use henceforth were assembled, arranged and calculated by the author of this dissertation, using a raw dataset pulled from http://water.usgs.gov/watuse/data/2005/usco2005.txt, which is available to the public.

Colorado, in million gallons per day (Mgal/d), million gallons per year (Mgal/yr), as well as thousand acre-feet per day and thousand acre-feet per year.

Table 3.1 Water withdrawals by water-use category in Colorado, 2005

Water-use category	% of total withdrawals	Withdrawals			
		Mgal/d	Mgal/yr	Thousand acre-feet/d	Thousand acre-feet/yr
Irrigation-Crop	90.11%	12,280.35	4,482,327.75	37.716	13,766.272
Domestic, public supplied	3.89%	529.51	193,271.15	1.626	593.581
Industrial, public-supplied	2.46%	334.66	122,150.90	1.028	375.154
Industrial, self-supplied	1.05%	142.44	51,990.60	0.437	159.675
Thermoelectric	0.90%	123.21	44,971.65	0.378	138.118
Aquaculture	0.65%	87.99	32,116.35	0.270	98.637
Irrigation-Golf	0.30%	40.64	14,833.60	0.125	45.557
Domestic, self-supplied	0.25%	34.43	12,566.95	0.106	38.596
Livestock	0.24%	33.06	12,066.90	0.102	37.060
Mining	0.16%	21.42	7,818.30	0.066	24.012
Total withdrawals	100%	13,627.71	4,974,114.15	41.85	15,276.66

The USGS water withdrawals data also reported the total population of Colorado to be 4,665,177 in 2005. Out of which, 4,366,577, or 93.5% of the population relied on public supply for their domestic water needs, and 298,600 or 6.5% of the population self-supplied their domestic water.

While USGS collected data on the withdrawals from each use category, however, not all of the water withdrawn are consumed during the production process. For example, there is a considerable amount of return flow from irrigated crop water withdrawals, also much of the water withdrawals for the thermoelectric sectors are for recirculation and cooling purposes, and therefore they are not all consumed. USGS classified consumptive use as part of the "water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment (Ivahnenko and Flynn 2010)". For the state of Colorado, USGS reported the consumptive use withdrawals for the irrigated crop, thermoelectric power generation and self-supplied domestic withdrawals categories along with the total withdrawal volumes (Ivahnenko and Flynn 2010). Tables 3.1.1 shows the consumptive uses of water withdrawals, and are used in the calculation in the method section.

Table 3.1.1 Consumptive water withdrawals by water-use category in Colorado, 2005

Water-use category	% of total consumption	Consumptive Withdrawals			
		Mgal/d	Mgal/yr	Thousand acre-feet/d	Thousand acre-feet/yr
Irrigation-Crop	84.58%	6,783.49	2,475,973.85	20.834	7,604.292
Domestic, public supplied	6.60%	529.51	193,271.15	1.626	593.581
Industrial, public-supplied	4.17%	334.66	122,150.90	1.028	375.154
Industrial, self-supplied	1.78%	142.44	51,990.60	0.437	159.675
Thermoelectric	0.54%	43.44	15,855.60	0.133	48.696
Aquaculture	1.10%	87.99	32,116.35	0.270	98.637
Irrigation-Golf	0.51%	40.64	14,833.60	0.125	45.557
Domestic, self-supplied	0.04%	3.44	1,255.60	0.011	3.856
Livestock	0.41%	33.06	12,066.90	0.102	37.060
Mining	0.27%	21.42	7,818.30	0.066	24.012
Total withdrawals	100%	8,020.09	2,927,332.85	24.63	8,990.52

The USGS only reports water use in these ten aggregated categories. At state levels, the regional economy often consists of over 300 sectors, many of which use water as a production input. The water use categories 'Industrial public supplied' and ‘industrial self supplied’ are in fact, a series of a few hundred sectors. In order to derive water values for most sectors in a regional economy, the USGS water use data needed to be further sub-divided. More specifically, to expand the aggregated ‘industrial’ category into sectors as close to the Input-Output model as possible. The approach is documented in the method section. Withdrawal in annual unit is used in this study, in order to match data from the Input-Output model (which is an annual snapshot of the economy).

3.2.2 The regional input-output model for Colorado

To fully take advantage of the value-added approach for estimating the benefits of water as an intermediate good, an I-O model is used to measure the sector-by-sector impacts. I-O is a static model, representing a simplified view of a local economy based on input-output tables and a regional income accounts, which represent the supply side and payment (input) side of an economy, respectively. On the supply side, an I-O account reflects the ways individual sector’s output in the area are distributed to household, investment, government, exports, and to other sectors as intermediate goods. On the payment, or input side, the regional income account represents how payments for inputs go to the factors of production such as wages, salaries, land and natural resources rents, interest and depreciation on capital, profits, imports, and to the producers of intermediate goods. There exist numerous software for constructing I-O models (Schaffer 1999): for instance, the IOPC (produced by the regional science research institute at West Virginia University), RIMS (The regional economic analysis division of the Bureau of Economic

Analysis), IMPLAN[17] (IMpact analysis for PLANning, by Minnesota IMPLAN Group, Inc.), and IO7 (produced by University of Queensland).

Economists at the USFS (Forest Service) developed IMPLAN in the 1980s as an in-house tool for its regional economic modeling analyses needs. After handing-over the software codes to contractors in 1993, IMPLAN became a proprietary system owned by the Minnesota IMPLAN group (MIG), which turned IMPLAN into commercial software available for purchase by the public. Today, USFS purchase agency-wide software licenses and data updates from MIG annually. Since the author of this dissertation has access to the IMPLAN software and data via a student-employment agreement with the USFS, this chapter will use IMPLAN in order to construct the statewide I-O model for Colorado.

Since the most recent USGS water withdrawals data available was from the year 2005, for consistency, IMPLAN software with 2006 data is used to construct the I-O model for the state of Colorado[18]. During model construction, the impact analysis area included all 64 counties in the state of Colorado. IMPLAN provides user the option of building state-wide model with an aggregated state-level data (i.e. one single data file for Colorado); alternatively, one can manually select all the counties that the state consists of. The two methods yield equivalent result. After building the state-wide model through regional multipliers, an industry summary report can be easily retrieved via the IMPALN

[17] MIG®, Inc., IMPLAN System (data: 2006, software: V3), 502 2nd Street, Suite 301, Hudson, WI 54016 www.implan.com

[18] Since 1990, MIG, Inc has been continuously releasing data updates on an annual basis, except for the year 2005.

software interface. Much of the required data for calculations (to be demonstrated in the method section) are found in this industry summary report, which shows sector by sector, the industry employment, output, labor income, and total value added for Colorado's regional economy. Since MIG® (Minnesota IMPLAN Group) forbids user from publishing any of their software's raw data, in order to honor the software and data license service agreement, this dissertation will not reprint each sector's jobs, output, labor income and value added amounts. However, Appendix 3.1 lists and ranks all of the sectors in the state of Colorado by employment size in each sector. Table 3.2 shows the top 20.

Table 3.2 Top 20 employed industries in Colorado (2006 IMPLAN)

Ranking	Industry Code	Sector
1	503	State & Local Education
2	481	Food services and drinking places
3	431	Real estate
4	390	Wholesale trade
5	504	State & Local Non-Education
6	33	New residential 1-unit structures
7	465	Offices of physicians dentists and other
8	439	Architectural and engineering services
9	38	Commercial and institutional buildings
10	454	Employment services
11	458	Services to buildings and dwellings
12	467	Hospitals
13	410	General merchandise stores
14	426	Securities- commodity contracts investments
15	405	Food and beverage stores
16	505	Federal Military
17	479	Hotels and motels- including casino hotels
18	470	Social assistance- except child day care
19	412	Non-store retailers
20	468	Nursing and residential care facilities

In 2006, there were 3.1 million people employed in the state, generating $442.9 billion in output, $155 billion in labor income and $251.2 billion in total value added. Before moving on to the method of disaggregation of the water withdrawal using IMPLAN data, it is beneficial to provide a brief summary of the data and sources IMPLAN uses to construct their base model here.

<u>Total value added</u> in the industry summary report is the value added to intermediate goods and services, which consists of (1) employee compensation –wages and salaries plus benefits paid by local industries; (2) proprietor income – income from

self-employment; (3) other property income – corporate income, rental income, interest and corporate transfer payments; and (4) indirect business taxes – sales, excise, fees, licenses and other taxes paid, including non-income based payments to the government. Labor income is all forms of employment income, including wages, benefits and proprietor income. Output is the value of production in producer's prices, in particular, it is sales adjusted for change in inventory for the manufacturing; sales for the service sectors; and gross margin (not gross sales) for the retail and wholesale trade sectors. Jobs as reported in IMPLAN are annual averages of both full and part time total wage and salary employees, as well as self-employed jobs; this method of counting employment is a standard convention and consistent with BLS's method, however, one cannot discern the number of hours worked or the proportion that is full time vs. part time (Olson and Lindall 2000). As with the rest of the data IMPLAN uses to construct their base model, employment numbers are taken and adjusted from government data sources. To get around the special sectors and non-disclosure issues (some sectors have incomplete county-level jobs reporting, while some are not require to disclose employee information), multiple sources are required to derive job counts for each sectors. These sources include: the Regional Economic Information System (REIS) program data from the Bureau of Economic Analysis, County Business Patterns (CBP) data, Economic Census and Annual Survey of Manufacturers from the Census Bureau, Quarterly Payroll File from the Internal Revenue Service (IRA), the Unemployment Insurance ES-202 Covered Employment and Wages Program data from the U.S. Department of Labor, Agricultural sectors data from the National Agricultural Statistical Service (NASS), and State and

Local Government Employment and Earnings data from the Annual Survey of Government Employment. IMPLAN derives commodity balance sheet (shows how a commodity from a given sector is used in all other sectors throughout the local economy, discussed at length in the next paragraph) for each sector from inter-industry and inter-institutional trade flow data. This is the heart of social accounting matrix (SAM) used in modern I-O models. Sources include the U.S. Benchmark I/O 'Make Table' from the Bureau of Economic Analysis, the Annual Revision of the U.S. National Income and Product Accounts from the Survey of Current Business by the U.S. Department of Commerce, Commodity Flow Survey from the Research and Innovative Technology Administration by the Bureau of Transportation Statistics (BTS), county-to-county distances by mode of transportation dataset from the Department of Energy's Oak Ridge National Labs (ORNL), in addition to IMPLAN's proprietary commodity supply and demand by county datasets (MIG 2010).

For this study, in order to disaggregate the ten USGS water use categories to match IMPLAN's 509 sectors as much as possible, a commodity balance sheet for the water supply sector is required (method shown in the next section). IMPLAN sector 32 (or commodity code 3032) represents the water supply industry, which is responsible for delivering treated or non-treated water in pipes or other delivery systems (i.e. ditches) to all other sectors that use water, including residential, business and government entities. The commodity balance sheet for this sector is of particular interests. The commodity balance sheet – shows how a commodity from a given sector is used in all other sectors throughout the local economy – is retrieved from the 2006 Colorado state-wide IMPLAN model. Table 3.3 shows which industries are purchasing commodities (delivered water and other water and sewage related services) from sector 32. Again, to honor MIG®'s software and data license service agreement, the actual gross absorption and inputs amount are not shown. Appendix 3.2 lists all sectors in Colorado that made a purchased from sector 32, ranked by the dollar amount purchased (gross input). Table 3.3 lists the top 20.

Table 3.3 Top 20 industries that purchased from sector 32

Ranking	Industry Code	Description
1	431	Real estate
2	499	Other State and local government enterprises
3	422	Telecommunications
4	498	State and local government electric utilities
5	479	Hotels and motels- including casino hotels
6	451	Management of companies and enterprises
7	481	Food services and drinking places
8	425	Nondepository credit intermediation
9	11	Cattle ranching and farming
10	390	Wholesale trade
11	450	All other miscellaneous professional and technical
12	467	Hospitals
13	478	Other amusement- gambling- and recreation industry
14	33	New residential 1-unit structures- all
15	460	Waste management and remediation services
16	491	Religious organizations
17	19	Oil and gas extraction
18	203	Iron and steel mills
19	27	Drilling oil and gas wells
20	456	Travel arrangement and reservation services

Out of 451 sectors that exist in Colorado, a total of 260 sectors in Colorado purchased from this sector 32 (See Appendix 3.2 for the full list). In IMPLAN's commodity balance sheet under ‘industry demand’, the gross input column indicates the total purchase of delivered water by each sector, while the gross absorption column represents the value of the water purchased as input by individual sector expressed as a proportion of total dollars outlays for the sector. In other words, if sector *i* is water system and sector *j* is oilseed farming, gross $absorption_j$ is the value of gross $input_{i,\, j}$ (value of intermediate goods from *i* to *j*) divided by $output_j$. Or, arranging, gross $absorption_j$ * $output_j$ = gross $input_{i,\, j}$. As an intuitive example, the oilseed farming sector demanded $137,488 worth of delivered water from sector 32; and the gross absorptions coefficient indicates that 0.5581% of the value of oilseeds final products is the cost of that delivered water. Total industry demand, or the sum of the ‘gross input’ column ($427,791,609), is the value of delivered water and related services demanded by all sectors of the economy (excluding household). These are pertinent information for assigning the proportion of value added attributable to water in the method section.

In addition to industry demand for water, sector 32’s commodity balance sheet also reports the institutional demand for the commodity, describing how households, state, local and federal government consume the commodity (delivery water). The numbers of household fall within each group were retrieved from the 2006 Colorado state-wide IMPLAN model’s area demographics report. The 50 – 75k group is the largest and demanded $124 million (2006 USD) worth of delivered water and related services from the sector. The rests of the household income group’s gross demand and numbers are not reprinted here to honor MIG®’s license agreement. These data are used to calculate the amount of public supplied water withdrawals by residential demand.

3.2.3 State and forest levels water contribution data

In order to demonstrate a method of calculating the economic contributions attributable to water originating from individual national forest, obviously, the actual volumes of water flowing out of the national forests are required. Brown and Froemke (2009) have estimated the annual contribution to water supply from all national forests in the continental U.S. It is the only water yields estimates available at the forest levels. These estimates were based on Brown et al.'s (2008) modeling effort, which used state-of-the-art hydrological models and Geographic Information System, and is likely the most accurate estimates of overall U.S. water supply available to date. All numbers and percentages found in tables and texts henceforth are arranged and calculated using data found in the Appendix in Brown et al. (2008) and Brown and Froemke (2009). The water supply in Colorado originates from forest cover type (41.9%), rangeland (50.1%), agricultural lands (2.25%), wetland / fresh water bodies (0.99%) and other land cover types (4.76%). In terms of land ownerships, besides national forests within the state (68.19%), Colorado's water supply also originates from Bureau of Land Management lands (6.69%), National Parks Service lands (2.21%), Bureau of Indian Affairs lands (0.47%), other federal agencies' lands (0.33%) and state and private lands (22.19%). Table 3.4 shows the actual volume of water supply of Colorado in terms of million cubic meters per year ($Mm^3/year$) by origins.

Table 3.4 Water supply (Mm3 and thousand acre-ft / year) of Colorado

By land ownership

	Volume (Mm3 / yr)	Volume (Thousand acre-ft / yr)	Percentage Total
NFS	15384	12472.012	68.19%
BLM	1509	1223.366	6.69%
NPS	478	387.521	2.12%
BIA	107	86.746	0.47%
Other Federal	75	60.803	0.33%
State & Private	5006	4058.430	22.19%
Total	22559	18288.87894	100.00%

By land cover type

	Volume (Mm3 / yr)	Volume (Thousand acre-ft / yr)	Percentage Total
Forest	9453	7663.672	41.90%
Rangeland	11301	9161.870	50.10%
Agriculture	508	411.842	2.25%
Water/Wetland	224	181.600	0.99%
Other	1073	869.895	4.76%
Total	22559	18288.879	100.00%

Table 3.5 lists all the national forest units in Colorado and their mean annual contributions to Colorado's water supply. The percent state total is calculated by dividing the water volume from each forest by 22,559 Mm3 (the state's total water yield). The Grand Mesa-Uncompahgre-Gunnison national forests contribute the most, making up 15.31% of the state's water supply; while Pawnee (a national grassland) contributes only 12 Mm^3/yr, or 0.05% of the state's water supply. This table lists only national forests

within the boarder of Colorado, see Brown and Froemke (2009) for the full list of all national forests in the U.S. and their water yields.

Table 3.5 Mean annual contributions to Colorado's water supply from national forests within the state

National Forest Unit	Water Volume (Mm3 / yr)	Water Volume (thousand acre-ft / yr)	Percent state total
Arapaho-Roosevelt	1,474	1194.991	6.53%
Grand Mesa-Uncompahgre-Gunnison	3,454	2800.203	15.31%
Routt	677	548.853	3.00%
Pawnee	12	9.729	0.05%
Pike-San Isabel	1,493	1210.395	6.62%
Rio Grande	2,043	1656.287	9.06%
San Juan	1,565	1268.766	6.94%
White River	2,267	1837.887	10.05%

The total water volume from table 3.4 differs slightly from the sum of NFS water volume from table 3.5 (a total of 10,527 thousand acre-ft from Colorado's NFS). This is because estimates from table 3.5 are the results of a more recent update by Brown and Froemke (2009), in which they overlaid the most recent boundaries for the national forest units obtained in July 2009 onto the hydro-geospatial model in Brown et al. (2008).

3.3 Method

3.3.1 Estimating direct water withdrawals for Colorado's IMPLAN sectors

There are 451 sectors in the 2006 Colorado state-wide IMPLAN model, while the USGS reported only ten aggregate water-use categories (Table 3.1.1). Following methods developed by Blackhurst et al. (2010), the industrial water use category was disaggregated and allocated to all economic sectors, allowing this study to take full advantage of the detailed data resolution offered in IMPLAN's I-O model.

3.3.1.1 Industrial public-supplied withdrawals

As seen in the 2005 USGS withdrawals data (table 3.1 and table 3.1.1), total industrial water withdrawals in 2005 was 477Mgal/d, 70% (334.66 Mgal/d) of which were public-supplied, while the rest (142.44 Mgal/d) were self-supplied. The task at hand is to allocate that 344.66 Mgal/d of water (122,150 Mgal/year) to all sectors in the IMPLAN model that purchased public-supplied water. Blackhurst et al. (2010) estimated water withdrawals for all industrial sectors in the U.S. with a 2002 national I-O table and 2000 USGS water withdrawal data. Modifying their method to fit the case of Colorado (with updated data: 2006 IMPLAN model and 2005 USGS water data):

$$\textit{Public-Supplied Withdrawal}_{IMPLANSector\ \boldsymbol{i}} = \frac{Sector\ i\ Purchase\ from\ Sector\ 32}{Total\ Industry\ Demand\ of\ Sector\ 32} * \textit{USGSPublic-Supplied} \qquad \textbf{(3.1)}$$

Equation 3.1 determines how much public-supplied industrial water each IMPLAN sector used. *Sector i purchase from sector 32* is the 'gross input' column for each sector in table 3.3 or Appendix 3.2; while the *total industry demand of sector 32* is the sum of that 'gross input' column ($427,791,609); *USGS public-supplied* is 122,150 Mgal/yr (from Table 3.1).

The IMPLAN model for Colorado indicates that only 260 sectors in the state purchased from sector 32 (having non-zero values under the 'gross input' column from sector 32), a closer examination revealed that most of them are manufacturing sectors. Industries having zero gross input from sector 32 are not indicative of zero water used; it merely reflects that they do not rely on public delivery, since an overwhelming majority of water withdrawals associated with these sectors is likely self-supplied (Blackhurst et al. 2010). The following section documents the method used to allocate the USGS self-supplied water withdrawal volume to all sectors with zero public-supplied withdrawal.

3.3.1.2 Industrial self-supplied withdrawals

Table 3.1 revealed that 30% (142.44 Mgal/d) of the total industrial water withdrawals in 2005 were self-supplied water. The task at hand is to allocate that 142.44 Mgal/d of water (51,990 Mgal/yr or 159.675 thousand acre-feet/yr) to all sectors in the IMPLAN model that do not purchase from sector 32. The U.S. stopped collecting and reporting industrial water use data since 1982; this motivated Blackhurst et al. (2010) to devise an approach of scaling Canadian industrial water data in order to disaggregate the self-supplied industrial water withdrawals for the U.S. Adapting Blackhurst et al.'s approach using Colorado's 2006 employment data:

$$Industrial\ self\text{-}withdrawal_{IMPLANSector\ i} =$$

$$\frac{CA\ Withdrawals\ i}{CA\ Employees\ i} * CO\ Employees_i * \frac{USGS\ Industrial\ Self-Supplied}{\sum CO\ Employees * \frac{CA\ Withdrawals\ i}{CA\ Employees\ i}} \qquad \textbf{(3.2)}$$

Table 3.6 reveals that Canadian manufacturing sectors' water withdrawals (withdrawals per employee ratio) rate for the food, beverage, paper, petro/coal, chemical and primary metal industries were very high compared to the rests. This heterogeneity associated with industrial water uses among industries forms the rationale behind the application of Blackhurst et al.'s method (Equation 3.2). The method scales Canada's manufacturing sectors' water use to sectors in the U.S. I adapted this method for the case of Colorado (instead of using Blackhurst et al.'s national employment data, I retrieved Colorado's employment numbers in IMPLAN). Essentially, the Canadian water withdrawals data are scaled by the number of employees in order to estimate the *Industrial self-withdrawal* for each sector in Colorado. The first term $\frac{CA\ Withdrawals\ i}{CA\ Employees\ i}$ is the Canadian water use per employee for Canadian sectors *i*; $CO\ Employees_i$ is the number of employees for sector *i* in Colorado; while *USGS Industrial Self-Supplied* is 159.675 thousand acre-feet (from Table 3.1). The last column in Table 3.6 contains the results: the estimated water withdrawals for Colorado's manufacturing industries by applying Blackhurst et al.'s allocation method. Since these estimates are the results from applying equation 3.2 (scaling Canada's water withdrawals with Colorado's employees numbers), it is neither meaningful nor appropriate to compare the water use per employee ratio across sectors between Canada and Colorado.

Table 3.6 Water use and number of employees by industry group for Canada and Colorado

Industry Group	Water Withdrawals in Canada (Thousand acre-feet/yr)[19]	Number of Employees in Canada[20]	Number of Employees in Colorado	Estimated Water Withdrawals in Colorado (Thousand acre-feet/yr)
Food	245.006	219,530	17,828	17.746
Beverage and tobacco	52.878	25,266	5,833	5.806
Textile mills	4.055	9,585	176	0.175
Textile products	2.271	10,515	1,944	1.935
Wood	71.936	100,683	7,134	7.101
Paper	1,595.010	64,135	2,154	2.144
Petroleum and coal	337.379	13,570	563	0.560
Chemicals	390.500	79,063	7,284	7.251
Plastics and rubber	19.626	105,658	5,777	5.751
Non-metallic minerals	32.278	49,640	9,964	9.918
Primary metals	1,404.504	70,940	2,232	2.222
Fabricated metals	21.897	174,188	15,751	15.679
Machinery	4.055	145,675	9,497	9.454
Computers and electronics	5.353	84,531	27,313	27.188
Electrical products	3.893	43,505	2,197	2.187
Transportation equipment	18.815	183,023	13,743	13.680
Miscellaneous	4.461	57,758	11,915	11.860
Others manufacturing	18.734	192,912	19,038	18.951
Total	4,232.652	1,630,177	160,343	159.609

[19] StatCan (2005)

[20] Industry Canada (2005)

3.3.1.3 Other public and self-supplied withdrawals

Other than the industrial self-supplied withdrawals, the rests of the USGS categories are conveniently corresponding to a handful of IMPLAN's sectors, in which case the IMPLAN sectors are aggregated to match the USGS categories. The USGS's irrigated crop category is matched with ten crop sectors. USGS thermoelectric withdrawals are matched with IMPLAM sector *30: power generation and supply* and sector *498: state and local government electric utilities*. USGS aquaculture withdrawal is embedded within IMPLAN sector *13: Animal production except cattle and poultry*. USGS golf irrigation water withdrawal is embedded within IMPLAN sector *478: Other amusement gambling and recreation*. USGS livestock withdrawal is matched with IMPLAN sector *11: cattle ranching and farming*, and sector *12: poultry and egg production*. Lastly, USGS mining withdrawal is matched with ten IMPLAN extraction sectors[21].

The USGS estimate of the total domestic public-supplied withdrawals in Colorado is further broken down into nine income groups:

$$\textit{Public-supplied Domestic}_{IncomeClass\ i} = \textit{USGS Domestic Public supplied} * \frac{\textit{Household Purchase from Sector } 32_{IncomeClass\ i}}{\sum_{i=1}^{9} \textit{Household Purchase from Sector } 32_{IncomeClass\ i}} \quad \textbf{(3.3)}$$

[21] USGS included oil and gas extraction as part of their mining water withdrawals for Colorado (Lovelace 2009), therefore, sectors *19: oil and gas extraction*, 27: *drilling oil and gas well,* and *28: support activities for oil and gas operation* are included in the aggregated 'mining' water category as well.

where, $\textit{Public-supplied Domestic}_{IncomeClass\ i}$ is the quantity of water used by each of the nine IMPLAN household income class; $USGS\ Domestic\ Public\ supplied$ is the total domestic public-supplied withdrawals in Colorado (593.581 thousand acre-feet/yr); $Household\ Purchase\ from\ Sector\ 32_{IncomeClass\ i}$ is the gross demand for delivered water by each of the none IMPLAN income class; while $\sum_{i=1}^{9} Household\ Purchase\ from\ Sector\ 32_{IncomeClass\ i}$ is the sum of household gross demand for delivered water in Colorado. Water withdrawals per household by income class are calculated by dividing Public-supplied $\text{Domestic}_{\text{IncomeClass}}$ with the number of household belonging in each income class. Domestic self-supplied withdrawals is as reported by the USGS (3.85 thousand acre-feet of consumptive withdrawals), since demographic data is not available to further break down this user group.

3.3.1.4 Total water withdrawals by sectors

While not all sectors rely on public supplied water, some self-supplied sectors do purchase from public supply, and vice versa. On top of this, a few sectors that conveniently bridged with USGS withdrawal categories also receive public supplied water. Therefore numerous combinations exist. But conceptually, the total water withdrawal by each sector *i* in Colorado (W_j) is the summation of *Public-Supplied withdrawal* (if any), *Industrial self-withdrawal* (if any), *and Other USGS Categories withdrawal* (if any).

$$W_j = \textit{Public-Supplied Withdrawal}_{IMPLANSector\ i} + \textit{Industrial self-withdrawal}_{IMPLANSector\ i} + \textit{Other\_USGS\_Categories withdrawal}_{IMPLANSector\ i} \quad \textbf{(3.3.1)}$$

3.3.2 Calculating the value-added, jobs, output and income per unit of water

The concepts of an I-O model and the traditional 'value-added' method, as discussed at length in sections 3.1.3.3 and 3.2.2, express the value of water as the ratio of quantity water used over some economic measures such as output and value-added. In its simplest form, Lichty and Anderson (1985) considered the value-added of water (P_j) as:

$$P_j = V_j / W_{j,} \qquad \textbf{(3.4)}$$

where, P_j is the imputed value of water per unit to sector j; V_j is the total value added by sector j, W_j is the total volume of water withdrawals by sector j. Besides value added, in order to paint a more complete picture of the economic contribution per unit water used, this chapter also uses job, output (total sales) and labor income respectively for each IMPLAN sector in the calculation.

3.3.3 Calculating the economic contribution of water

Young (2005; 2010) emphasized deductive methods used to impute the value of water such as the value-added approach implicitly omit important cost elements (i.e. land, labor, and other non-water inputs) from residual calculation, thus overstating the value of water. This is because of the term V_j from equation 3.4 includes employee compensation, proprietor income, indirect business taxes and other property income, which the production process required inputs (intermediate goods and services) from other sectors in the region. Claiming P_j as the imputed value of water for sector j in essence ignores all non-water inputs necessary for production and it is analogous to assuming zero opportunity cost for all non-water inputs (i.e. labor[22], capital). For this reason, P_j in actuality is the value added of all inputs per unit water used, and not the traditionally assumed 'value of water'.

This chapter employs a novel approach to account for the issue mentioned above. Recall from section 3.2.2 that the gross absorptions coefficient indicates the proportion of the value of a given sector's products that is accredited to the cost of a production input (in this case, delivered water and related services from sector 32). Equation 3.5 scales down P_j (from equation 3.4) to reflect only the proportional economic value attributable to water related inputs. Equation 3.5.1 shows what the $\textit{Gross absorption}_{Sector32,\,j}$ term represent (the percentage of the value of sector *j*'s value that is the cost of delivered water purchased from sector 32.

$$\textit{Water Impacts}_{\,j} = \frac{Vj}{Wj} * \textit{Gross absorption}_{Sector32,\,j} \qquad \textbf{(3.5)}$$

$$\textit{Water Impacts}_{\,j} = \frac{Vj}{Wj} * \frac{\textit{Gross Input}_{Sector32,j}}{\textit{Output}_j} \qquad \textbf{(3.5.1)}$$

After this small adjustment from equation 3.4, $\textit{Water Impacts}_{\,j}$ is the economic measure (value added, income, employment or output) attributed to water use in sector *j*, where

[22] This contrasts with the traditional method of valuating the economic impacts of water for irrigated farming. Bergman and Boussard (1976, p.86) explicitly made the case that labor cost should be ignored when evaluating the profitability of farms, and the value added calculation which assumed zero opportunity cost for labor is valid especially when the majority of manpower is provided by family members, or when the unemployment rate is high.

$Gross\ absorption_{Sector32,\ j}$ is the value of the water purchased as a production input by sector *j* expressed as a proportion of total dollars outlays for the sector.

3.3.4 Calculating the economic contribution of water originating from National Forests

To proxy the portion of $Water\ Impacts_{\ j}$ that is attributable to water originating from the national forest system in Colorado, water contribution data from Table 3.5 are used:

$$Water\ contribution_{\ j,\ NFS} = Water\ Impacts_{\ j} * Percent\ state\ total_{NFS} \qquad \textbf{(3.6)}$$

The economic contribution to sector j that is attributed to water originating from the national forest system in Colorado – $Water\ contribution_{\ j,\ NFS}$ – is the product of $Water\ Impacts_{\ j}$ and the percent of annual contributions to Colorado's water supply from all of the national forests within the state boundary: $Percent\ state\ total_{NFS}$.

3.4 Results

3.4.1 Direct water withdrawals for Colorado's IMPLAN sectors

Applying equations 3.1 and 3.2, the amount of water use for a total of 142 industries and ten residential groups are estimated from the USGS reported withdrawals categories. Table 3.7 displays the results sorted by consumptive water withdrawals:

Table 3.7 Disaggregated water withdrawals for 2006 Colorado's IMPLAN sectors (ranked by water withdrawals)

	IMPLAN sector	Estimated water withdrawals (thousand acre-ft /yr)
1-10	Irrigated crop farming	7,611.898
	Households 50-75k	130.549
13	Animal production - except cattle and poultry including Aquaculture	99.461
	Households 35-50k	90.466
	Households 75-100k	87.006
	Households 100-150k	80.761
30, 498	Power generation	67.392
431	Real estate	63.401
	Households 25-35k	56.812
	Households 150k+	56.040
478	Other amusement- gambling- and recreation (Golf Courses)	53.306
11-12	Cattle, poultry and egg	46.571
	Households 15-25k	46.508
499	Other State and local government enterprises	38.979
19-29	Mining, including oil and gas	33.613
302-324	Computers and electronics	27.351
	Households LT10k	24.800
422	Telecommunications	22.920
	Households 10-15k	20.640
46-84	Food Manufacturing	17.927
224-256	Fabricated metals	15.707
344-361	Transportation equipment	13.725
479	Hotels and motels- including casino hotels	13.645
451	Management of companies and enterprises	12.942
481	Food services and drinking places	11.518
374-389	Miscellaneous	11.342
182-202	Non-metallic minerals	9.973
425	Nondepository credit intermediation	9.903
257-301	Machinery	9.516

	IMPLAN sector	Estimated water withdrawals (thousand acre-ft /yr)
390	Wholesale trade	8.899
450	All other miscellaneous professional and tech	8.781
467	Hospitals	8.018
147-171	Chemical	7.888
33	New residential 1-unit structures- all	7.694
460	Waste management and remediation services	7.321
85-91	Beverage	7.221
112-123	Wood	7.135
203-223	Primary metals	6.827
491	Religious organizations	5.924
172-181	Plastics and rubber	5.764
456	Travel arrangement and reservation services	4.176
446	Scientific research and development services	4.094
468	Nursing and residential care facilities	3.929
421	Cable networks and program distribution	3.921
	Self-supplied domestic	3.856
439	Architectural and engineering services	3.607
426	Securities- commodity contracts- investments	3.013
466	Other ambulatory health care services	2.983
459	Other support services	2.981
465	Offices of physicians- dentists- and other health services	2.809
401	Motor vehicle and parts dealers	2.704
480	Other accommodations	2.315
410	General merchandise stores	2.231
325-343	Electrical products	2.201
38	Commercial and institutional buildings	2.189
124-135	Paper	2.149
489	Dry-cleaning and laundry services	2.050
398	Postal service	1.985
99-103	Textile products	1.938

	IMPLAN sector	Estimated water withdrawals (thousand acre-ft /yr)
404	Building material and garden supply stores	1.757
496	Other Federal Government enterprises	1.737
483	Automotive repair and maintenance- except car	1.725
470	Social assistance- except child day care	1.581
493	Civic- social- professional and similar organ	1.568
458	Services to buildings and dwellings	1.461
469	Child day care services	1.358
455	Business support services	1.341
408	Clothing and clothing accessories stores	1.240
430	Monetary authorities and depository credit institute	1.225
476	Fitness and recreational sports centers	1.163
482	Car washes	1.108
434	Machinery and equipment rental and leasing	1.012
412	Non-store retailers	0.976
43	Maintenance and repair of nonresidential	0.957
490	Other personal services	0.888
402	Furniture and home furnishings stores	0.876
437	Legal services	0.845
438	Accounting and bookkeeping services	0.835
487	Personal care services	0.829
417	Software publishers	0.782
440	Specialized design services	0.739
444	Management consulting services	0.727
409	Sporting goods- hobby- book and music stores	0.714
407	Gasoline stations	0.691
463	Other educational services	0.681
406	Health and personal care stores	0.679
142-146	Petroleum and coal	0.671
394	Truck transportation	0.662
477	Bowling centers	0.624
416	Database- directory- and other publishers	0.619
41	Other new construction	0.618

	IMPLAN sector	Estimated water withdrawals (thousand acre-ft /yr)
428	Insurance agencies- brokerages- and related	0.618
424	Data processing services	0.584
35	New residential additions and alterations-all	0.566
400	Warehousing and storage	0.528
447	Advertising and related services	0.485
411	Miscellaneous store retailers	0.483
391	Air transportation	0.472
472	Spectator sports	0.442
452	Office administrative services	0.433
418	Motion picture and video industries	0.424
475	Museums- historical sites- zoos- and parks	0.409
435	General and consumer goods rental except vide	0.398
432	Automotive equipment rental and leasing	0.372
42	Maintenance and repair of farm and nonfarm re	0.365
488	Death care services	0.341
453	Facilities support services	0.335
395	Transit and ground passenger transportation	0.325
461	Elementary and secondary schools	0.317
39	Highway- street- bridge- and tunnel construct	0.298
34	New multifamily housing structures- all	0.292
413	Newspaper publishers	0.292
485	Commercial machinery repair and maintenance	0.284
442	Computer systems design services	0.276
420	Radio and television broadcasting	0.271
44	Maintenance and repair of highways- streets-	0.241
492	Grantmaking and giving and social advocacy or	0.238
40	Water- sewer- and pipeline construction	0.238
464	Home health care services	0.237
31	Natural gas distribution	0.211
497	State and local government passenger transit	0.207
471	Performing arts companies	0.204
393	Water transportation	0.203

	IMPLAN sector	Estimated water withdrawals (thousand acre-ft /yr)
484	Electronic equipment repair and maintenance	0.199
45	Other maintenance and repair construction	0.195
403	Electronics and appliance stores	0.193
397	Scenic and sightseeing transportation and sup	0.193
449	Veterinary services	0.192
392	Rail transportation	0.191
423	Information services	0.180
92-98	Textile mills	0.177
448	Photographic services	0.171
473	Independent artists- writers- and performers	0.163
399	Couriers and messengers	0.159
433	Video tape and disc rental	0.155
462	Colleges- universities- and junior colleges	0.146
414	Periodical publishers	0.133
457	Investigation and security services	0.125
37	Manufacturing and industrial buildings	0.109
474	Promoters of performing arts and sports and a	0.096
454	Employment services	0.075
415	Book publishers	0.062
441	Custom computer programming services	0.060
443	Other computer related services	0.042
	Total	8,990.521

Note these disaggregated water withdrawals across all sectors and household groups consistently summed to the USGS total consumptive withdrawals for Colorado (8,990,521 acre-ft/yr).

3.4.2 The economic impacts of water to sectors

Applying equations 3.4 and 3.5, the economic impacts of water to 142 sectors in Colorado are estimated and sorted by total value-added per Mgal (Table 2.8):

Table 3.8 Economic impacts of water in jobs, output (2005 US$), labor income and value-added per thousand acre-ft (TAF) water used, ranked by value-added

	IMPLAN sector	Jobs/ TAF	Output / TAF	Labor Income / TAF	Value added / TAF
19-29	Mining, including oil and gas	3.70	2,191,037	551,317	1,356,753
30, 498	Power generation	3.09	1,502,317	323,465	1,132,832
442	Computer systems design	12.11	1,140,310	1,025,100	991,564
428	Insurance agencies- brokerages- and related	8.99	1,140,310	491,747	973,202
454	Employment services	38.63	1,140,310	979,658	971,974
441	Custom computer programming	12.68	1,140,310	1,061,537	969,209
147-171	Chemical	5.33	3,673,698	481,409	937,884
403	Electronics and appliance stores	21.82	1,140,310	740,358	935,606
398	Postal service	16.87	1,140,310	871,810	910,922
397	Scenic and sightseeing transportation and sup	13.69	1,140,310	801,371	905,783
400	Warehousing and storage	14.73	1,140,310	703,345	863,232
472	Spectator sports	12.90	1,140,310	681,903	861,647
419	Sound recording industries	2.26	1,140,310	169,629	857,188
411	Miscellaneous store retailers	34.09	1,140,310	616,200	856,103
443	Other computer related services	6.35	1,140,310	406,785	849,821
412	Non-store retailers	22.95	1,140,310	236,451	846,864
457	Investigation and security services	27.51	1,140,310	741,634	829,998
430	Monetary authorities and depository credit institute	5.36	1,140,310	277,662	815,330
465	Offices of physicians-	10.43	1,140,310	688,847	809,929

	IMPLAN sector	Jobs/ TAF	Output / TAF	Labor Income / TAF	Value added / TAF
431	Real estate	5.92	1,140,310	188,329	800,256
453	Facilities support services	17.31	1,140,310	680,594	786,773
407	Gasoline stations	13.83	1,140,310	354,024	780,292
390	Wholesale trade	6.10	1,140,310	431,940	769,007
45	Other maintenance and repair construction	14.90	1,140,310	829,910	766,370
401	Motor vehicle and parts dealers	9.95	1,140,310	534,481	758,500
464	Home health care services	23.90	1,140,310	650,700	752,843
468	Nursing and residential care facilities	22.45	1,140,310	719,951	752,649
437	Legal services	8.79	1,140,310	590,658	741,172
405	Food and beverage stores	17.12	1,140,310	512,492	732,523
479	Hotels and motels- including casino hotels	14.01	1,140,310	413,872	730,790
402	Furniture and home furnishings stores	11.94	1,140,310	421,146	728,907
425	Nondepository credit intermediation	6.85	1,140,310	475,181	725,927
399	Couriers and messengers	17.61	1,140,310	507,018	722,530
451	Management of companies and enterprises	5.02	1,140,310	556,056	716,586
461	Elementary and secondary schools	30.85	1,140,310	717,344	716,218
469	Child day care services	29.19	1,140,310	441,852	715,512
404	Building material and garden supply stores	12.31	1,140,310	443,694	713,185
435	General and consumer goods rental except vide	17.15	1,140,310	701,796	712,222
395	Transit and ground passenger transportation	18.56	1,140,310	517,081	712,054
409	Sporting goods- hobby- book and music stores	25.08			
413	Newspaper publishers	7.30	1,140,310	475,847	707,078
493	Civic- social- professional and similar organ	24.12	1,140,310	531,340	705,903
406	Health and personal care stores	20.23	1,140,310	897,710	699,893

	IMPLAN sector	Jobs/ TAF	Output / TAF	Labor Income / TAF	Value added / TAF
410	General merchandise stores	19.87	1,140,310	505,772	694,857
417	Software publishers	2.10	1,140,310	489,413	689,071
489	Dry-cleaning and laundry	26.70	1,140,310	377,872	688,873
460	Waste management and remediation services	4.46	1,140,310	593,449	683,217
496	Other Federal Government enterprises	60.98	1,140,310	401,731	682,219
463	Other educational services	19.11	1,140,310	916,415	681,411
424	Data processing services	3.64	1,140,310	490,403	678,336
446	Scientific research	8.03	1,140,310	487,469	673,763
452	Office administrative services	5.21	1,140,310	760,703	666,600
455	Business support services	18.65	1,140,310	393,925	666,075
482	Car washes	23.74	1,140,310	518,279	662,135
41	Other new construction	10.78	1,140,310	366,078	661,361
37	Manufacturing and industrial buildings	11.34	1,140,310	589,928	660,095
416	Database- directory- and other	1.96	1,140,310	620,592	659,491
422	Telecommunications	1.68	1,140,310	246,018	655,877
470	Social assistance- except child	34.14	1,140,310	266,487	649,315
491	Religious organizations	6.35	1,140,310	654,051	642,571
459	Other support services	8.76	1,140,310	207,187	634,783
477	Bowling centers	22.10	1,140,310	345,069	630,631
38	Commercial and institutional buildings	10.34	1,140,310	372,395	630,069
408	Clothing and clothing	15.05	1,140,310	558,142	629,129
476	Fitness and recreational sports	36.64	956,377	309,657	629,101
439	Architectural and engineering services	9.02	1,140,310	566,890	628,776
488	Death care services	18.81	1,140,310	623,621	626,795
39	Highway- street- bridge- and tunnel construct	9.29	1,140,310	539,265	625,250
462	Colleges- universities- and junior colleges	19.97	1,140,310	516,968	625,106
444	Management consulting services	8.00	1,140,310	601,644	615,040
438	Accounting and bookkeeping	11.77	1,140,310	596,447	612,007
467	Hospitals	10.12	1,140,310	566,781	604,126

	IMPLAN sector	Jobs/ TAF	Output / TAF	Labor Income / TAF	Value added / TAF
31	Natural gas distribution	0.80	1,140,310	548,352	603,954
423	Information services	2.49	1,140,310	249,858	595,144
475	Museums- historical sites- zoos- and parks	16.74	1,140,310	418,979	594,234
34	New multifamily housing	8.94	1,140,310	682,685	590,664
485	Commercial machinery repair and maintenance	8.75	1,140,310	480,374	585,496
466	Other ambulatory health care services	7.75	1,140,310	361,442	582,897
458	Services to buildings and dwellings	21.43	1,140,310	416,747	576,142
484	Electronic equipment repair and maintenance	7.79	1,140,310	462,487	573,740
483	Automotive repair and maintenance- except car	13.15	1,140,310	360,735	572,652
40	Water- sewer- and pipeline construction	8.51	1,140,310	433,174	566,179
445	Environmental and other technical consulting	7.08	1,140,310	469,499	562,372
481	Food services and drinking places	22.42	1,140,310	424,014	554,269
414	Periodical publishers	4.19	1,140,310	385,591	547,297
456	Travel arrangement and	8.10	1,140,310	355,192	541,919
394	Truck transportation	8.94	1,140,310	368,738	541,716
486	Household goods repair	6.28	1,140,310	398,885	524,454
421	Cable networks and program distribution	0.79	1,140,310	174,312	517,933
434	Machinery and equipment rental and leasing	3.38	1,140,310	77,543	515,722
43	Maintenance and repair of nonresidential building	8.60	1,140,310	214,789	506,688
420	Radio and television broadcasting	5.14	1,140,310	465,953	505,259
433	Video tape and disc rental	21.90	1,140,310	491,382	494,570
440	Specialized design services	8.50	1,140,310	346,688	491,070
490	Other personal services	6.73	1,140,310	392,096	486,622
492	Grantmaking and giving and social advocacy or	23.43	1,140,310	152,275	484,422
499	Other State and local	4.84	1,140,310	935,061	478,655

	IMPLAN sector	Jobs/ TAF	Output / TAF	Labor Income / TAF	Value added / TAF
35	New residential additions and alterations-all	5.77	1,140,310	275,006	477,046
432	Automotive equipment rental and leasing	6.72	1,140,310	307,070	476,226
415	Book publishers	3.49	1,140,310	249,726	476,211
426	Securities- commodity	8.79	1,140,310	289,041	470,151
447	Advertising and related services	9.64	1,140,310	533,174	470,108
449	Veterinary services	16.91	1,140,310	411,552	451,383
448	Photographic services	16.51	1,140,310	465,850	439,367
33	New residential 1-unit structures- all	7.02	1,140,310	309,264	438,817
42	Maintenance and repair of farm and nonfarm re	7.62	1,140,310	379,975	436,337
497	State and local government passenger transit	17.82	1,140,310	413,611	429,202
450	All other miscellaneous professional and tech	2.39	1,140,310	951,867	425,640
391	Air transportation	4.95	1,140,310	89,168	412,954
471	Performing arts companies	58.60	1,140,310	342,336	401,296
203-223	Primary metals	1.66	1,140,310	422,828	397,749
418	Motion picture and video	6.71	1,266,377	194,167	381,314
473	Independent artists- writers- and performers	19.27	1,140,310	282,774	318,646
85-91	Beverage	0.91	1,140,310	239,844	278,060
429	Funds- trusts- and other financial vehicles	4.17	756,734	84,421	263,017
17	Hunting and trapping	9.92	1,140,310	189,446	188,250
44	Maintenance and repair of highways- streets-	2.03	1,140,310	34,585	158,486
182-202	Non-metallic minerals	0.94	194,495	112,009	114,942
478	Other amusement- gambling- and recreation (Golf Courses)	1.89	243,979	59,943	103,373
46-84	Food Manufacturing	1.37	165,757	57,185	101,739
15	Forest nurseries- forest products- and timber	2.25	555,507	64,457	99,394

	IMPLAN sector	Jobs/ TAF	Output / TAF	Labor Income / TAF	Value added / TAF
11-12	Cattle, poultry and egg	2.43	1,140,310	28,975	78,580
124-135	Paper	0.42	395,662	28,438	46,040
325-343	Electrical products	0.32	134,834	30,068	37,394
257-301	Machinery	0.30	93,254	21,628	34,706
112-123	Wood	0.46	101,399	19,416	27,410
104-108, 109-111, 136-141, 362-373	Other manufacturing	0.36	76,963	17,002	27,318
224-256	Fabricated metals	0.25	43,808	16,940	23,527
344-361	Transportation equipment	0.14	55,119	13,707	21,045
172-181	Plastics and rubber	0.10	59,390	15,922	18,532
302-324	Computers and electronics	0.08	26,530	5,999	9,903
92-98	Textile mills	0.18	46,382	8,428	8,830
1-10	Irrigated crop farming	0.07	40,287	6,842	7,923
99-103	Textile products	0.07	9,453	2,109	5,385
374-389	Miscellaneous	0.02	10,605	2,532	3,228
13	Animal production - except cattle and poultry including Aquaculture	0.17	3,268	1,074	1,495
393	Water transportation	0.05	17,443	113	228

The above table exhibits that, for example, each thousand acre-foot of water used by the ‘other animal production –aquaculture’ sector in Colorado support 0.17 job, $$9,447 in output, $1,369 in labor income and $1,607 in total value added in that sector. Note that the sectors with relative low impacts (for example textile mills, irrigated crop farming, etc.) stemmed from two reasons, it could be due to the sector's extreme high volume of water use, or, it could be due to the sector having a small work force / output to begin with.

Notice that output/TAF values are $1,140,309 for a number of sectors. Those sectors only withdrew water from public supply (sector 32). When self-supplied water is zero, the value of water in terms of output/Mgal for sector *j* is effectively:

$$Water\ Impact_j = \frac{Output\ j}{\frac{Gross\ input_{i,j}}{Total\ Industry\ Demand\ of\ Sector\ 32} * USGSPublicSupplied} * Gross\ absorption_j.$$

(3.7)

Since gross input$_{i,j}$ = gross absorption$_j$ * output$_j$ (explained in section 3.2.2), applying this relationship to equation 3.7, canceling terms and rearranging:

$$Water\ Impact_j = \frac{Total\ Industry\ Demand\ of\ Sector\ 32}{USGSPublicSupplied}. \qquad \textbf{(3.8)}$$

Since the results are a vector of constant values across all sectors, using this method to derive economic contribution of water to output (output/TAF) does not produce meaningful result. Output/TAF values are dropped from subsequent results and tables.

While households demand delivered water, however, as institutional sectors, they do not produce output, therefore, jobs, labor income and value-added do not exist in the IMPLAN model. Nevertheless, equation 3.3 is applied to calculate the quantity of water used per household by income class (Table 3.9) to reveal the positive relationship between income and water use. Recall in Table 3.7 that households in the 50-75k income class withdrew the most water, however, Table 3.9 here shows the 150k+ income class has the highest per household withdrawal.

Table 3.9 Per household domestic public-supplied water withdrawals

IMPLAN income class	Acre-ft/household
Households LT10k	0.185477
Households 10-15k	0.214556
Households 15-25k	0.215110
Households 25-35k	0.234000
Households 35-50k	0.276169
Households 50-75k	0.319015
Households 75-100k	0.378228
Households 100-150k	0.459382
Households 150k+	0.560015

3.4.3 Marginal economic contribution of water originating from Colorado's National Forests

Applying equation 3.6, the marginal economic impacts of water originating from national forests are estimated. Table 3.10 shows the results from all national forests within the states of Colorado (which contributes to 57.56% of Colorado's annual water supply). It exhibits that, for example, each thousand acre-ft of water originating from

Colorado's national forests contributes to 2.13 jobs, $1.2 million in labor income and $0.3 million in total value-added for the 'mining, including oil and gas' sector in Colorado.

Table 3.10 Marginal economic impacts of water (per thousand acre-ft) from CO's NFS (2005 US$)

	IMPLAN sector	Jobs / TAF	Labor Income (2005 US$) / TAF	Value added (2005 US$) / TAF
19-29	Mining, including oil and gas	2.13	317,339.16	780,949.68
30, 498	Power generation	1.78	186,187.28	652,060.36
442	Computer systems design services	6.97	590,049.36	570,746.04
428	Insurance agencies- brokerages- and related	5.18	283,050.61	560,177.00
454	Employment services	22.24	563,892.58	559,469.86
441	Custom computer programming services	7.30	611,022.81	557,878.32
147-171	Chemical	3.07	277,099.89	539,847.85
403	Electronics and appliance stores	12.56	426,151.34	538,536.49
398	Postal service	9.71	501,815.17	524,328.34
397	Scenic and sightseeing transportation and sup	7.88	461,270.62	521,370.17
400	Warehousing and storage	8.48	404,846.54	496,877.87
472	Spectator sports	7.42	392,504.68	495,965.50
419	Sound recording industries	1.30	97,638.52	493,399.12
411	Miscellaneous store retailers	19.62	354,685.82	492,774.58
443	Other computer related services	3.65	234,146.12	489,158.56
412	Non-store retailers	13.21	136,101.80	487,456.30
457	Investigation and security services	15.83	426,885.79	477,748.45
430	Monetary authorities and depository credit institute	3.08	159,822.69	469,305.28
465	Offices of physicians- dentists- and other health services	6.01	396,501.68	466,196.81
431	Real estate	3.41	108,402.23	460,628.88
474	Promoters of performing arts sports	26.17	233,136.53	452,950.68

	IMPLAN sector	Jobs / TAF	Labor Income (2005 US$) / TAF	Value added (2005 US$) / TAF
453	Facilities support services	9.97	391,750.97	452,868.16
407	Gasoline stations	7.96	203,777.04	449,137.18
390	Wholesale trade	3.51	248,625.50	442,641.84
45	Other maintenance and repair construction	8.57	477,697.80	441,123.66
401	Motor vehicle and parts dealers	5.72	307,648.07	436,594.05
464	Home health care services	13.76	374,544.10	433,337.84
468	Nursing and residential care facilities	12.92	414,404.98	433,226.21
437	Legal services	5.06	339,983.56	426,620.01
405	Food and beverage stores	9.85	294,991.56	421,641.37
479	Hotels and motels- including casino hotels	8.06	238,225.51	420,643.97
402	Furniture and home furnishings stores	6.87	242,412.25	419,560.11
425	Nondepository credit intermediation	3.94	273,515.02	417,844.79
399	Couriers and messengers	10.14	291,840.64	415,889.67
451	Management of companies and enterprises	2.89	320,066.76	412,468.43
461	Elementary and secondary schools	17.76	412,904.26	412,256.06
469	Child day care services	16.80	254,330.82	411,849.97
404	Building material and garden supply stores	7.08	255,390.84	410,510.70
435	General and consumer goods rental except vide	9.87	403,954.97	409,956.45
395	Transit and ground passenger transportation	10.68	297,632.46	409,859.76
409	Sporting goods- hobby- book and music stores	14.44	273,898.12	406,995.50
413	Newspaper publishers	4.20	305,840.25	406,318.88
493	Civic- social- professional and similar organ	13.88	516,723.55	402,859.36
406	Health and personal care stores	11.64	291,123.29	399,961.12
410	General merchandise stores	11.44	281,707.01	396,630.51
417	Software publishers	1.21	217,504.02	396,516.59
489	Dry-cleaning and laundry services	15.37	341,590.00	393,260.78
392	Rail transportation	2.43	224,941.52	392,758.33
460	Waste management and remediation services	2.57	231,236.93	392,686.35

	IMPLAN sector	Jobs / TAF	Labor Income (2005 US$) / TAF	Value added (2005 US$) / TAF
496	Other Federal Government enterprises	35.10	527,490.17	392,221.53
463	Other educational services	11.00	282,276.96	390,451.56
424	Data processing services	2.10	280,588.11	387,819.05
446	Scientific research and development services	4.62	437,862.26	383,695.98
452	Office administrative services	3.00	226,743.77	383,394.01
455	Business support services	10.73	298,322.32	381,126.17
482	Car washes	13.66	210,714.87	380,680.33
41	Other new construction	6.20	339,563.32	379,952.04
37	Manufacturing and industrial buildings	6.53	357,213.99	379,604.12
416	Database- directory- and other publishers	1.13	141,608.64	377,523.78
422	Telecommunications	0.97	153,390.58	373,746.96
470	Social assistance- except child day care service	19.65	376,473.11	369,864.86
491	Religious organizations	3.66	119,256.91	365,381.94
459	Other support services	5.04	198,622.20	362,992.23
477	Bowling centers	12.72	214,350.93	362,668.96
38	Commercial and institutional buildings	5.95	321,267.37	362,127.73
408	Clothing and clothing accessories stores	8.67	178,239.36	362,111.84
476	Fitness and recreational sports centers	21.09	326,302.61	361,924.80
439	Architectural and engineering services	5.19	358,957.07	360,784.29
488	Death care services	10.83	310,401.60	359,894.73
39	Highway- street- bridge- and tunnel construct	5.35	297,567.72	359,812.13
462	Colleges- universities- and junior colleges	11.49	346,307.13	354,018.31
444	Management consulting services	4.60	343,315.88	352,272.56
438	Accounting and bookkeeping services	6.77	326,240.05	347,735.80
467	Hospitals	5.82	315,632.23	347,636.87
487	Personal care services	12.78	241,002.61	347,496.44
31	Natural gas distribution	0.46	143,818.77	342,566.08
423	Information services	1.43	241,164.94	342,042.03
475	Museums- historical sites- zoos- and parks	9.63	392,954.65	339,987.35

	IMPLAN sector	Jobs / TAF	Labor Income (2005 US$) / TAF	Value added (2005 US$) / TAF
34	New multifamily housing structures-all	5.15	276,504.00	337,012.74
485	Commercial machinery repair and maintenance	5.04	208,046.65	335,516.57
466	Other ambulatory health care services	4.46	239,880.35	331,628.45
458	Services to buildings and dwellings	12.34	266,208.08	330,245.91
484	Electronic equipment repair and maintenance	4.48	207,639.80	329,619.55
483	Automotive repair and maintenance-except car	7.57	249,335.75	325,893.82
40	Water- sewer- and pipeline construction	4.90	270,244.57	323,702.16
445	Environmental and other technical consulting	4.07	244,063.08	319,038.31
481	Food services and drinking places	12.91	221,946.72	315,025.24
414	Periodical publishers	2.41	204,448.88	311,929.65
456	Travel arrangement and reservation services	4.66	212,246.47	311,812.90
394	Truck transportation	5.14	229,599.12	301,876.44
486	Household goods repair and maintenance	3.61	100,334.46	298,123.29
421	Cable networks and program distribution	0.45	44,633.76	296,850.39
434	Machinery and equipment rental and leasing	1.94	123,632.84	291,650.74
43	Maintenance and repair of nonresidential building	4.95	268,203.20	290,827.98
420	Radio and television broadcasting	2.96	282,840.25	284,675.43
433	Video tape and disc rental	12.61	199,554.28	282,660.84
440	Specialized design services	4.89	225,691.41	280,100.25
490	Other personal services	3.88	87,650.03	278,834.39
492	Grantmaking and giving and social advocacy or	13.49	538,223.02	275,514.44
480	Other accommodations	6.81	150,827.57	274,785.34
499	Other State and local government enterprises	2.78	158,294.06	274,588.51
35	New residential additions and alterations-all	3.32	176,750.29	274,116.72

	IMPLAN sector	Jobs / TAF	Labor Income (2005 US$) / TAF	Value added (2005 US$) / TAF
432	Automotive equipment rental and leasing	3.87	143,742.81	274,108.08
415	Book publishers	2.01	166,372.57	270,619.91
426	Securities- commodity contracts- investments	5.06	306,895.78	270,594.89
447	Advertising and related services	5.55	236,889.99	259,817.13
449	Veterinary services	9.74	268,144.33	252,900.45
448	Photographic services	9.50	178,013.05	252,584.12
33	New residential 1-unit structures- all	4.04	218,714.02	251,156.22
42	Maintenance and repair of farm and nonfarm re	4.39	238,075.33	247,049.60
497	State and local government passenger transit	10.25	547,896.60	244,999.11
450	All other miscellaneous professional and tech	1.37	51,325.20	237,697.09
391	Air transportation	2.85	197,049.16	230,986.93
471	Performing arts companies	33.73	243,380.68	228,944.93
203-223	Primary metals	0.95	111,763.07	219,485.22
418	Motion picture and video industries	3.86	162,765.22	183,413.18
473	Independent artists- writers- and performers	11.09	138,054.55	160,051.59
85-91	Beverage	0.52	48,593.09	151,393.32
429	Funds- trusts- and other financial vehicles	2.40	109,045.47	108,356.91
17	Hunting and trapping	5.71	19,907.17	91,224.89
44	Maintenance and repair of highways- streets-	1.17	64,472.60	66,160.70
182-202	Non-metallic minerals	0.54	34,503.26	59,501.58
478	Other amusement- gambling- and recreation (Golf Courses)	1.09	32,915.69	58,560.98
46-84	Food Manufacturing	0.79	37,101.71	57,211.12
15	Forest nurseries- forest products- and timber	1.29	16,678.27	45,230.76
142-146	Petroleum and coal	0.08	22,551.61	44,358.96
11-12	Cattle, poultry and egg	1.40	16,368.93	26,500.90

	IMPLAN sector	Jobs / TAF	Labor Income (2005 US$) / TAF	Value added (2005 US$) / TAF
124-135	Paper	0.24	17,307.34	21,524.12
325-343	Electrical products	0.18	12,449.03	19,976.87
257-301	Machinery	0.17	11,175.77	15,777.17
112-123	Wood	0.26	9,786.18	15,724.29
104-108, 109-111, 136-141, 362-373	Other manufacturing	0.21	9,750.50	13,542.20
224-256	Fabricated metals	0.15	7,889.73	12,113.60
344-361	Transportation equipment	0.08	9,164.89	10,666.84
172-181	Plastics and rubber	0.06	3,452.92	5,700.04
302-324	Computers and electronics	0.05	4,851.43	5,082.51
92-98	Textile mills	0.11	3,938.04	4,560.52
1-10	Irrigated crop farming	0.04	1,213.93	3,099.40
99-103	Textile products	0.04	1,457.52	1,857.87
374-389	Miscellaneous	0.01	618.46	860.58
13	Animal production - except cattle and poultry including Aquaculture	0.10	788.53	614.48
393	Water transportation	0.03	65.30	131.76

On average, across all sectors in Colorado, each thousand acre-ft of water originating from Colorado's national forests contributes to 942 jobs, $33 million in labor income and $45 million in total value-added to the state's economy.

One might be tempted to calculate the **total** economic impacts by using the above marginal impacts with the total volume of water from national forests in Colorado. However, since the volume of water used by each industry is different, a method to allocate the volume of water originating from national forests that get used by each sector in the economy is required. To properly estimate the **total** economic contributions of water from all of Colorado's national forests, one would needs the marginal impacts of water for each sector above (Table 3.10), the water withdrawals from each sector (Table 3.7), along with the total volume of water originating from all of the national forest lands in Colorado in an average year (from Table 3.5):

$$Total\ impacts_{\ IMPLAN\ Sector\ j} =$$

$$\left(\frac{Water\ Withdrawal\ j}{\sum Water\ withdrawasls} * Water\ contribution_{\ CO\_NFS} \right) * Marginal\ water\ impacts_{\ j} \qquad \textbf{(3.9)}$$

The first term in equation 3.9 gives the withdrawal volume as a percentage of totals from each sector. Multiplying that with water volume contributions from Colorado's national forests, in effect, proxies the relative amount of water each sector use that was from Colorado's national forest lands. Lastly, multiplying this with the marginal water impacts from each sector (Table 3.10), the total economic impacts of water is estimated:

Table 3.11 Total economic impacts of water (per thousand acre-ft) from CO's NFS (2005 US$)

	IMPLAN sector	Jobs	Labor Income (2005 US$)	Value added (2005 US$)
19-29	Mining, including oil and gas	145.51	21,698,470.27	30,736,230.49
30, 498	Power generation	243.78	25,524,819.52	51,454,407.24
442	Computer systems design services	3.91	330,986.19	184,283.54
428	Insurance agencies- brokerages- and related	6.50	355,589.69	405,072.21
454	Employment services	3.37	85,531.55	48,845.97
441	Custom computer programming services	0.89	74,273.63	39,033.62
147-171	Chemical	49.23	4,446,354.53	4,986,102.59
403	Electronics and appliance stores	4.93	167,183.80	121,609.52
398	Postal service	39.20	2,026,142.58	1,218,573.30
397	Scenic and sightseeing transportation	3.09	180,893.52	117,688.90
400	Warehousing and storage	9.11	435,159.28	307,418.20
472	Spectator sports	6.67	352,801.66	256,601.60
419	Sound recording industries	0.08	6,260.63	18,210.31
411	Miscellaneous store retailers	19.26	348,183.70	278,442.18
443	Other computer related services	0.32	20,187.68	24,275.67
412	Non-store retailers	26.22	270,182.02	556,993.80
457	Investigation and security services	4.01	108,199.07	69,700.07
430	Monetary authorities and depository credit institute	7.68	398,173.39	672,994.24
465	Offices of physicians- dentists- and other health services	34.32	2,265,726.41	1,533,394.26
431	Real estate	439.38	13,981,000.34	34,195,841.23
474	Promoters of performing arts and sports	5.10	45,397.58	50,768.62
453	Facilities support services	6.79	266,830.08	177,549.15
407	Gasoline stations	11.19	286,241.18	363,143.24
390	Wholesale trade	63.52	4,500,610.05	4,612,116.81
45	Other maintenance and repair construction	3.40	189,543.72	100,748.51
401	Motor vehicle and parts dealers	31.49	1,692,361.41	1,382,416.27

	IMPLAN sector	Jobs	Labor Income (2005 US$)	Value added (2005 US$)
464	Home health care services	6.63	180,485.65	120,195.56
468	Nursing and residential care facilities	103.27	3,311,934.41	1,992,937.13
437	Legal services	8.70	584,528.28	422,192.91
405	Food and beverage stores	44.89	1,343,963.17	1,105,714.73
479	Hotels and motels- including casino hotels	223.85	6,612,261.17	6,720,452.59
402	Furniture and home furnishings stores	12.24	431,885.32	430,259.22
425	Nondepository credit intermediation	79.44	5,510,160.18	4,845,294.12
399	Couriers and messengers	3.28	94,414.88	77,445.28
451	Management of companies and enterprises	76.02	8,426,590.13	6,250,634.62
461	Elementary and secondary schools	11.46	266,549.54	153,185.53
469	Child day care services	46.42	702,696.70	654,983.06
404	Building material and garden supply stores	25.31	912,735.53	844,473.90
435	General and consumer goods rental except vide	7.99	327,034.98	191,038.58
395	Transit and ground passenger transportation	7.07	197,019.44	156,165.89
409	Sporting goods- hobby- book and music stores	20.97	397,772.63	340,218.21
413	Newspaper publishers	2.50	181,548.83	138,831.47
493	Civic- social- professional and similar organ	44.27	1,647,864.31	739,500.99
406	Health and personal care stores	16.08	401,910.17	317,827.84
410	General merchandise stores	51.90	1,278,342.81	1,035,995.58
417	Software publishers	1.93	345,972.77	363,043.03
489	Dry-cleaning and laundry services	64.08	1,424,401.05	943,908.46
392	Rail transportation	0.94	87,417.88	87,857.37
460	Waste management and remediation services	38.26	3,443,554.80	3,366,027.99
496	Other Federal Government enterprises	124.03	1,863,978.67	797,774.42
463	Other educational services	15.25	391,288.61	311,538.02
424	Data processing services	2.49	333,392.22	265,239.04
446	Scientific research and development	38.48	3,646,842.29	1,839,453.56

	IMPLAN sector	Jobs	Labor Income (2005 US$)	Value added (2005 US$)
452	Office administrative services	2.64	199,673.37	194,335.54
455	Business support services	29.28	813,651.47	598,333.81
482	Car washes	30.79	474,884.72	493,827.82
41	Other new construction	7.80	426,829.26	274,906.05
37	Manufacturing and industrial buildings	1.45	79,508.82	48,633.99
416	Database- directory- and other publishers	1.42	178,428.44	273,804.61
422	Telecommunications	45.13	7,151,824.96	10,030,393.66
470	Social assistance- except child day care	63.20	1,210,687.66	684,641.68
491	Religious organizations	44.05	1,437,171.58	2,534,511.30
459	Other support services	30.58	1,204,500.90	1,267,064.69
477	Bowling centers	16.14	271,887.95	264,787.26
38	Commercial and institutional buildings	26.50	1,430,506.02	928,126.06
408	Clothing and clothing accessories stores	21.86	449,572.56	525,727.90
476	Fitness and recreational sports centers	49.92	772,283.58	493,056.51
439	Architectural and engineering services	38.07	2,633,651.75	1,523,651.23
488	Death care services	7.52	215,460.53	143,794.20
39	Highway- street- bridge- and tunnel construct	3.24	180,098.94	125,349.69
462	Colleges- universities- and junior colleges	3.42	103,025.91	60,622.36
444	Management consulting services	6.81	507,782.18	299,905.55
438	Accounting and bookkeeping services	11.51	554,359.80	340,115.14
467	Hospitals	94.98	5,148,167.90	3,263,768.14
487	Personal care services	21.56	406,638.50	337,488.69
31	Natural gas distribution	0.20	61,672.43	84,555.52
423	Information services	0.53	88,517.96	72,263.47
475	Museums- historical sites- zoos- and parks	8.02	327,133.08	162,917.18
34	New multifamily housing structures	3.06	164,460.09	115,379.20

	IMPLAN sector	Jobs	Labor Income (2005 US$)	Value added (2005 US$)
485	Commercial machinery repair and maintenance	2.91	120,306.18	111,676.89
466	Other ambulatory health care services	27.06	1,455,737.41	1,158,409.91
458	Services to buildings and dwellings	36.66	791,016.54	564,837.97
484	Electronic equipment repair and maintenance	1.82	84,194.48	76,932.19
483	Automotive repair and maintenance-except car	26.57	875,133.92	658,397.56
40	Water- sewer- and pipeline construction	2.37	130,762.75	90,156.03
445	Environmental and other technical consulting	5.56	333,129.21	250,654.54
481	Food services and drinking places	302.40	5,200,247.78	4,248,569.83
414	Periodical publishers	0.65	55,366.59	48,623.01
456	Travel arrangement and reservation services	39.59	1,802,974.82	1,524,633.17
394	Truck transportation	6.92	309,017.26	233,864.25
486	Household goods repair and maintenance	1.57	43,626.80	74,614.15
421	Cable networks and program distribution	3.63	355,971.72	1,362,736.10
434	Machinery and equipment rental and leasing	4.00	254,585.77	345,688.93
43	Maintenance and repair of nonresidential building	9.63	522,056.40	325,845.54
420	Radio and television broadcasting	1.63	155,932.36	90,337.30
433	Video tape and disc rental	3.97	62,854.38	51,246.27
440	Specialized design services	7.35	339,216.42	242,324.56
490	Other personal services	7.00	158,307.65	289,879.99
492	Grantmaking and giving and social advocacy or	6.54	261,084.39	76,928.12
480	Other accommodations	32.06	710,424.59	744,994.27
499	Other State and local government enterprises	220.82	12,551,406.02	12,532,341.72
35	New residential additions and alterations-all	3.82	203,498.53	181,659.77
432	Automotive equipment rental leasing	2.93	108,733.28	119,349.41

	IMPLAN sector	Jobs	Labor Income (2005 US$)	Value added (2005 US$)
415	Book publishers	0.25	20,930.95	19,596.97
426	Securities- commodity contracts- investments	31.00	1,880,724.19	954,499.91
447	Advertising and related services	5.47	233,501.01	147,411.69
449	Veterinary services	3.81	104,957.01	56,978.96
448	Photographic services	3.31	61,999.08	50,636.25
33	New residential 1-unit structures- all	63.23	3,423,210.34	2,262,679.41
42	Maintenance and repair of farm and nonfarm	3.26	176,704.77	105,545.60
497	State and local government passenger transit	4.33	231,173.27	59,501.19
450	All other miscellaneous professional and tech	24.54	916,771.56	2,443,860.71
391	Air transportation	2.74	189,018.23	127,537.71
471	Performing arts companies	14.02	101,176.16	54,782.92
203-223	Primary metals	13.26	1,552,208.92	1,754,604.49
418	Motion picture and video industries	3.33	140,422.05	91,080.70
473	Independent artists- writers- and performers	3.67	45,716.59	30,507.40
85-91	Beverage	7.71	713,844.00	1,280,140.41
429	Funds- trusts- and other financial vehicles	0.03	1,172.74	670.77
17	Hunting and trapping	0.21	721.85	1,904.03
44	Maintenance and repair of highways- streets-	0.57	31,624.47	18,679.71
182-202	Non-metallic minerals	10.93	699,987.43	694,833.36
478	Other amusement- gambling- and recreation (Golf Courses)	117.69	3,569,289.86	3,655,184.84
46-84	Food Manufacturing	28.75	1,352,996.39	1,200,895.68
15	Forest nurseries- forest products- and timber	0.04	533.96	833.52
142-146	Petroleum and coal	0.11	30,776.27	34,845.12
11-12	Cattle, poultry and egg	132.37	1,550,720.53	1,445,093.36
124-135	Paper	1.07	75,658.14	54,159.26

	IMPLAN sector	Jobs	Labor Income (2005 US$)	Value added (2005 US$)
325-343	Electrical products	0.81	55,727.53	51,473.50
257-301	Machinery	3.32	216,338.02	175,795.02
112-123	Wood	3.83	142,044.40	131,372.43
104-108, 109-111, 136-141, 362-373	Other manufacturing	7.91	376,073.20	300,647.06
224-256	Fabricated metals	4.65	252,098.93	222,794.48
344-361	Transportation equipment	2.32	255,891.37	171,429.86
172-181	Plastics and rubber	0.70	40,487.45	38,471.05
302-324	Computers and electronics	2.57	269,929.29	162,772.35
92-98	Textile mills	0.04	1,415.93	943.84
1-10	Irrigated crop farming	642.08	18,796,940.18	27,624,573.87
99-103	Textile products	0.15	5,746.50	4,216.26
374-389	Miscellaneous	0.22	14,269.52	11,429.06
13	Animal production - except cattle and poultry including Aquaculture	20.16	159,540.86	71,562.29
393	Water transportation	0.01	26.98	31.33

Summing across all sectors, water originating from Colorado's national forests contribute to a <u>total</u> of 4,738 jobs, $215,473,985 in labor income, and $264,485,290 in value-added for Colorado's state economy annually.

This approach is only defensible when one aims to estimate the overall impacts from water originating **from all national forest lands in Colorado** to Colorado's state economy as a whole. This is an important point because in most geographic locations, water withdrawn or diverted from a supply point often originates from a <u>source</u> that crosses state line, or even from a few states away. Colorado is different because it is a headwater state. Except for the Green, Little Snake and the Cimarron rivers that flow into the state boundary for relatively short distances[23], Colorado does not receive any water from another state (Freed 2003). This is unique to the geography and hydrology of Colorado, therefore making the calculation (equation 3.9) in this chapter defensible and possible at all. To be more specific, Brown et al.'s (2008) water supply model (in Table 3.5) claims that 57.6% of the water supply in Colorado originates from Colorado's NFS lands; one can be reasonably confident to make the assertion that 57.6% of Colorado's water supply did came from NFS lands.

Prior to the discussion in the next section, it is worth pointing out first an important caveat. The calculation performed above has one sole objective: accounting for

[23] The Green River rises from Wyoming, flowing south to Utah, then it briefly crosses the extreme western portion of Moffat County, CO before flowing back into Utah; The Little Snake River actually raises from Routt County, CO, but it meanders and crossing the state line of Colorado and Wyoming a few times before flowing back into Moffat County, CO; The Cimarron River flows from New Mexico to Oklahoma, in the process crosses the extreme southeastern corner of Baca County, CO for a very short distance.

Colorado's national forest water's contribution **to the state's economy**. This is the advantage of utilizing USGS's consumptive-only withdrawal data (Table 3.1), for it does not concern with how much / where the water came from, nor how much is left / leaving the state, it only accounts for consumptive uses. Hence it is a valid approach when one is accounting for the benefits of water to Colorado's state economy as a whole. Certainly water that does not get withdrawn (and those not consumed completely plus return flow) in the state will eventually flow outside state line, thereby continue to provide services to other geographies. If, the objective is to account for the economic impact of all of the water originating from Colorado's national forests, in other words, to account for each sectors and geographies that benefited from every last drop of water that came from Colorado's national forests, additional flow data and hydrological model are needed. By the same token, to estimate the impacts attributable to water originating from an individual forests (such as those listed in Table 3.5), one would also need substantial geo-spatial and hydrological modeling. Section 3.5.1 provides additional discussion on estimating impacts from individual national forest.

3.5 Summary and conclusion

National forests contribute a substantial portion of water to the western U.S. In particular, the national forest systems in Colorado are estimated to provide more than half the water supply within the state. A customized value-added approach was used along with a state-wide input-output model to derive the marginal economic contributions to each economic sector in the state of Colorado. The approach used in this chapter differed from the traditionally applied method, in that it avoided over-estimating the value of water from implicitly assigning zero opportunity cost to all non-water inputs. Instead, the gross absorption coefficients for the water supply sector were used for adjusting the economic impacts. A method of calculating the economic contributions attributable to water originating from national forest in Colorado for each sector in the regional economy was demonstrated. On an average year, summing across all sectors, water originating from Colorado's national forests contributed to a total of 4,738 jobs, $215,473,985 in labor income, and $264,485,290 in value-added for Colorado's state economy as a whole.

3.5.1 Discussion and future direction

The method and results shown above demonstrated an approach of deriving the economic contributions from water originating from all national forests in Colorado. An extension to this research would be to derive the economic contributions from water originating from a specific forest. This could be of particular interest to district rangers, forest supervisors, regional foresters, national forest planners, and other officials who would like / need to showcase the economic benefits supported by resources flow (other than the traditional timber, range, mineral, recreation, etc.) from a specific forest management unit. To undertake this type of analysis, however, involve additional derivation processes and data requirement. Brown (2004) articulated this predicament aptly in his attempt to derive the marginal economic value (his focus was on water transaction value, not economic impacts) of water from national forests. Brown derived marginal water values for 18 large regions in the U.S but not for each individual forest. He stated that in order to get at forest-level values, one would need a flow routing model to simulate the flow, delivery and storage of water originating from a specific land mass. In the ecosystem services framework, service flow matters. Simply put, in order to derive the economic contributions from water originating from a specific forest, in addition to knowing the annual volume of water leaving a specific area, one would also require data on the physical amounts arriving at each diversion point (river reach), level of upstream uses, timing of delivery, upstream storage capacity, and the economic value of water to specific demands / user group when it finally reaches them. The involvedness and intricacy of such an analysis has been the rationales behind Brown's approach of only deriving economic values for 18 large regions of the U.S, as well as this dissertation's approach of deriving the economic contributions from water originating from all national forests within Colorado.

Young (2005) stressed the bias of some residual methods (e.g. value-added approach) in ignoring all non-water input cost and therefore producing higher estimated water impacts than other studies using econometric methods and observations on water markets. This study used gross absorption coefficients to discount a portion of the economic impacts (that are un-related to water inputs), and thereby avoided implicitly assigning zero opportunity cost to all non-water inputs and over-estimating the value. On the other hand, this approach is likely to have under-estimated the impacts of water for sectors that self-supplied the majority of their water input. Inputs owned by the firm such as equity capital, management and land are noncontractual inputs. Pricing noncontractual inputs are not straightforward since they are not bought and sold on the market, thus not well represented in an I-O model. Nevertheless they are scarce and valuable and carry opportunity costs for the firm, therefore should be accounted for when considering the value of water input (Young 2005). This point is pertinent to estimating water values in the western states, where water is often self-delivered by irrigators who possess water rights. These water right holders have options to irrigate their own crop, or they may choice to sell / lease the rights to other irrigators, municipalities, government entities or other users. These opportunity costs are potentially high. By using the gross absorption coefficients (in equation 3.5) in the derivation of water impacts for those sectors that self-deliver a majority of their water inputs ignores the opportunity costs of noncontractual inputs, hence potentially under-estimating the value of water. In contrasts, Young's (2005) also cautioned that ignoring other noncontractual and non-water inputs (e.g. equity capital, entrepreneurship, management, and land) would actually inflate the derived value of water.

This study used gross input and absorption rate for IMPLAN Sector 32 in order to estimate the sector-by-sector water withdrawals as well as to derive the economic value of water. This sector, however, also includes sewage and related services. As a consequence, the gross input and absorption rate used in this study are not purely from the final demand of delivered-water. Nevertheless, other services such as sewage and water treatment constitute only a small portion of sector 32. Since IMPLAN's sectoring scheme is based on the North American Industry Classification System (NAICS), upon examining IMPLAN sector 32's corresponding NAICS class – *2213 water supply* – from the U.S. economic census data (U.S. Census Bureau 2007), it is revealed that the final production of this industry made up of water (91.76% of total industry sales), irrigation system user charge (4.07%), sewage system user charge (2.96%) and other services (1.21%). Furthermore, if a sector requires sewage and water treatment services from sector 32, it is likely that this sector also had to use water as an input at some point during the production process. Overall, sector 32 remains a reliable proxy for the relative amount of water used by each sector in the economy.

This study focused on the economic contribution of water supply, in terms of contribution per quantity water used only and ignoring quality, which does not paint the full picture. Recall from the literature review that numerous studies on the economics of water quality deal with the non-market nature of water as an environmental goods. Quality of water supply is equally crucial and can have significant impacts to the regional economy. A meaningful future research direction might attempt to answer the question: how do employment, income or value added per unit of water change given different levels of raw water turbidity? For instance, water with high level of sediments requires additional treatment, adding to the cost of industrial production and / or provision of delivered water to domestic use. Higher cost of industrial production may reduces a sector's output level therefore their demands for commodity inputs from every other sectors in the regional economy. Higher treatment cost of delivered water translates into higher water fees paid by consumer, this in and of itself is a meaningful measure of the cost of water quality degradation. Issues related to these will become increasingly important in Colorado and other water scarce locations around the globe.

On a related note, this study viewed water as a uniformed input, implying that one Mgal of water used by the car wash industry is the same as one Mgal used by the oilseed industry. This is clearly a simplifying assumption. Water delivered to domestic household or breweries use might need to go through additional treatment; while water withdrew by irrigator or the power generation industry might not. This issue affects the unit cost of water input in sectors' production processes, and should be examined when taking water quality into accounts.

It is easy to incorrectly interpret the results from this study. The danger exists in using the derived employment/Mgal, income/Mgal or value-added/Mgal results for the purpose of ranking industries and / or to allocate water (i.e. in time of extreme draught) according to this ranking. Strictly speaking these per Mgal economic impacts are not exactly measures of water use efficiency. A sector with high employment/Mgal, income/Mgal or value-added/Mgal values is not necessary the reflection of high water productivity. Instead, any industry that uses a relatively small amount of water will achieve a high derived impact per unit water value. On the other hand, a sector with low employment/Mgal, income/Mgal or value-added/Mgal values is not necessary the reflection of low water productivity. Instead, sectors that use a relatively large amount of water will achieve a low derived impact per Mgal value, regardless of their true water-saving technology. Hence sector-by-sector results are not meant to be compared in such manner.

Another unintended connection that can be inappropriately made from this study concerns the relationship between increase timber harvest and water yield. While it was highlighted the fact that forest is critical to water yield, as well as the economic importance of water, this study does not advocate any specific forest management strategy for the purpose of increasing water yield. This point is raised because there have been emerging studies that suggest decreasing forest cover equals higher water yield (Elliot et al. 2010; AFRTG 2010). Decreasing forest cover, however, also potentially increases water flow's sediments and turbidity and increase the risk of flooding (which inhibits the timely release of water supply). It is beneficial to end this chapter here by repeating a main thesis from section 3.1: **quality** water in **predictable quantity** is one of the major ecosystem benefit provided by **intact** forest ecosystem.

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CONCLUDING CHAPTER

The introductory chapter used the ecosystem services framework to present water resources. By placing this all-important natural resource within the realm of ecosystem services such as Costanza et al.'s definition, one can begin to comprehend how many moving pieces are involved. It is not an overstatement to say that it would be a fruitless pursuit if the aim is to carry out a valuation exercise that claims to monetize the 'total' economic benefit of water. On the other hand, researchers could take comfort in having the revelation that any single piece of research on water's value is by default a partial valuation. More specifically: a valuation focusing on a particular benefit, to a particular user group, set in a specific geography and time horizon.

The United Nation's Millennium Ecosystem Assessment (2003) categorized ecosystem services into four categories: provisioning, regulating, cultural and supporting services. In the grand scheme of water related services, this dissertation research demonstrated the valuation of only two pieces within two of the categories: water supply (provisioning services) and recreation (cultural services as well as provisioning services: if anglers consume the catch). Other types of water ecosystem services such as regulating services and supporting services are no less important. However, it is actually not desirable to monetize each and every type of ecosystem services that water provides due to the danger of double counting (or multiple counting). Because the natural environment and raw materials that exist operate in an open system, it is never straightforward to demarcate a specific benefit, to a specific user group, at a given geographic location. It is worth discussing the intricate interplay between water, its benefits, and the natural system it resides in, because ecosystem services are complex geographically, economically, and ecologically (Ruhl et al. 2007).

The ecosystem is a complex, open, dynamic and adaptive system where the whole is more than the sum of its parts. Since linear relationship rarely exist in the natural environment, this complexity manifests itself onto the valuation of water resources and adds uncertainty to the process. The classic example is the ecosystem benefits originating from wetlands. Benefits derived from wetland (habitat and refugia provision, flood protection, etc.) are the results of a suite of ecosystem processes associated not only with the wetland itself, but with all linked ecosystems in the surrounding geography. For example, the source of water (tidal vs. spring fed) of the wetland, the plant communities, soil formations, and other biotic factors that make up the wetland. These factors all contribute to, and interact with, the function and benefits provided by the wetland – which is an open and dynamic system. Since many of the services and functions are not fully understood, therefore, uncertainties exist when a small change occur to any one of the factor. Since no one ecosystem is closed, and several smaller systems may exist within a larger one, they are interlinked and difficult to separate. In sum, a plot of wetland is what it is and where it is, the same apply to the services and benefits it provides. If, one acre of wetland has been estimated to provide $0.5 million worth of benefits to residents of a coastal community, two acres of the same wetland does not necessary equal to $1 million worth of benefits. On the same token, if one acre of wetland has been estimated to provide $1 million worth of benefits to residents of a coastal community, when only half of an acre is left intact, its benefits does not necessary equal to $0.5 million. Simply put, two acres of wetland may be able to produce a certain amount of benefits and services, but half that land mass by itself may not necessary be able to produce 50% of the benefits from the fully intact one. This reiterates the above mentioned concept of ecosystem connectivity. The conclusion is that these complex adaptive systems cannot simply be added up or aggregated together from a small scale level to arrive at large scale result.

The concept of a complex system apply aptly to the valuation of water supply's benefit to producer (as in Chapter 3) and provide a useful analogy, especially when adding the complexity of a regional economy and human behavior to the mix. For instance, results from Table 3.11 shows that the water supply originated from Colorado's national forests supported a total of $3,099 in value-added for the irrigated crop sector. This result is the product of numerous ecological factors as well as economic factors, interacting delicately in a specific economic and natural environment. If only half the water supply were to become available to irrigators, the contribution to value-added would not simply be half of $3,099. Numerous factors could affect the result. It may be true that since only half the water volume is now available to the entire state, producers would choose to irrigate only half their crop. However, they might also choose to switch to dry crop farming. If all irrigators in the state have decided to only water half their cropland, having half the inventory at harvest time may drive up the prices of crop. As one can see, numerous scenarios or combinations of scenarios are possible, and all of them would end up with a different result ($ value contributed from one acre-ft of water). It is easy to imagine that including the complexity of natural ecosystem (i.e. the effects of surrounding system such as forest soil on the quality of water) back into the mix would exponentially increase the numbers of combinations the above scenario brings. Because of the nature of complex system, as well as the ambiguities and uncertainties associated with ecosystem services and their values, techniques that aim to tease out simplifying relationships via statistical model (i.e. BTM, or Benefit Transfer Method) in order to extend result from one specific point in time / space to another may not be appropriate.

While water supply support different sectors in the economy as well as provide consumer surplus to recreational anglers, it is worth mentioning that possible trade-offs exist. It is true that water is a renewable resource in the sense that precipitation occurs overtime and groundwater recharges naturally. Nevertheless, in a seasonal context, it is very much a finite public good where rivalry and excludability exist. One more million gallons withdrew by one user is one million gallons less for another. A prime example was witnessed on the Western Slope of Colorado by the author during survey field work in the summer of 2009. Toward the end of the season, anglers and boaters on the Ridgway reservoir exhibited signs of gloom. Upon inquiry, it was revealed that irrigators requested withdrawals of water from the reservoirs throughout the summer and by the end of August, Ridgway reservoir was at 60% capacity (some section lower). This is both a common and reoccurring situation in the area. Upon further inquiries and observations, it was revealed that the fishing was not pleasant for the shoreline anglers for they had to relocate from their usual spot on the shore to a lower level of the reservoir; and boaters also felt restricted due to having a smaller surface area to navigate in. In fact, two ramps were closed at the Crawford reservoir because of low water level (one more was closed for the season but due to consolidating the zebra mussel inspection stations). Photographs taken by the author (Appendix 3.3) documented this state of affair. As irrigators withdrew water from Colorado's reservoirs (which they have the rights to the water from either Colorado's right-in first-right water law, or from leases and purchases later on) and supported the irrigated crop sectors in the state's economy, other non-consumptive users such as anglers are impacted as a result.

Relating to chapter 2, a possible extension of this research is to estimate the relationships between reservoir level, catch rate, visitations and the resulting consumer surplus. Knowing the relationships between reservoir water level and angler consumer surplus / regional economic effects and related trade-offs are meaningful information to communicate. More specifically, the question becomes: if withdrawing one million more gallons of water supports a certain numbers of jobs / income / value-added for the irrigated crop sectors, what is the loss in non-market benefits ($WTP/angler day) to angler, as well as the loss to local economies (from visitor expenditures)? This conveys potentially powerful information to stakeholders and policy makers alike. Because when water resources become scarcer in the near future, these types of tradeoffs will become more prominent, especially in the west. Studies focusing on these tradeoffs, as well as on more comprehensive water pricing strategies including the value of water's ecosystem services will be invaluable to natural resource managers and the public.

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Appendix 3.1 Ranking of industries by employment in Colorado

Ranking	Industry Code	Description
1	503	State & Local Education
2	481	Food services and drinking places
3	431	Real estate
4	390	Wholesale trade
5	504	State & Local Non-Education
6	33	New residential 1-unit structures- all
7	465	Offices of physicians- dentists- and other
8	439	Architectural and engineering services
9	38	Commercial and institutional buildings
10	454	Employment services
11	458	Services to buildings and dwellings
12	467	Hospitals
13	410	General merchandise stores
14	426	Securities- commodity contracts- investments
15	405	Food and beverage stores
16	505	Federal Military
17	479	Hotels and motels- including casino hotels
18	470	Social assistance- except child day care
19	412	Non-store retailers
20	468	Nursing and residential care facilities
21	401	Motor vehicle and parts dealers
22	430	Monetary authorities and depository credit in
23	494	Private households
24	422	Telecommunications
25	442	Computer systems design services
26	427	Insurance carriers
27	493	Civic- social- professional and similar organ
28	425	Nondepository credit intermediation
29	451	Management of companies and enterprises
30	478	Other amusement- gambling- and recreation
31	506	Federal Non-Military
32	411	Miscellaneous store retailers
33	437	Legal services
34	455	Business support services
35	394	Truck transportation
36	404	Building material and garden supply stores
37	483	Automotive repair and maintenance- except car
38	463	Other educational services
39	441	Custom computer programming services
40	408	Clothing and clothing accessories stores
41	438	Accounting and bookkeeping services
42	41	Other new construction
43	466	Other ambulatory health care services
44	446	Scientific research and development services

Ranking	Industry Code	Description
45	11	Cattle ranching and farming
46	444	Management consulting services
47	34	New multifamily housing structures- all
48	469	Child day care services
49	409	Sporting goods- hobby- book and music stores
50	428	Insurance agencies- brokerages- and related
51	487	Personal care services
52	398	Postal service
53	462	Colleges- universities- and junior colleges
54	457	Investigation and security services
55	499	Other State and local government enterprises
56	406	Health and personal care stores
57	19	Oil and gas extraction
58	417	Software publishers
59	399	Couriers and messengers
60	459	Other support services
61	391	Air transportation
62	407	Gasoline stations
63	476	Fitness and recreational sports centers
64	464	Home health care services
65	402	Furniture and home furnishings stores
66	447	Advertising and related services
67	492	Grantmaking and giving and social advocacy
68	39	Highway- street- bridge- and tunnel construct
69	472	Spectator sports
70	35	New residential additions and alterations-all
71	471	Performing arts companies
72	491	Religious organizations
73	43	Maintenance and repair of nonresidential
74	403	Electronics and appliance stores
75	449	Veterinary services
76	18	Agriculture and forestry support activities
77	354	Guided missile and space vehicle manufacturing
78	489	Dry-cleaning and laundry services
79	461	Elementary and secondary schools
80	397	Scenic and sightseeing transportation and sup
81	139	Commercial printing
82	413	Newspaper publishers
83	400	Warehousing and storage
84	474	Promoters of performing arts and sports and a
85	40	Water- sewer- and pipeline construction
86	450	All other miscellaneous professional and tech
87	429	Funds- trusts- and other financial vehicles
88	490	Other personal services
89	460	Waste management and remediation services

Ranking	Industry Code	Description
90	28	Support activities for oil and gas operations
91	395	Transit and ground passenger transportation
92	2	Grain farming
93	13	Animal production- except cattle and poultry
94	30	Power generation and supply
95	435	General and consumer goods rental
96	424	Data processing services
97	496	Other Federal Government enterprises
98	45	Other maintenance and repair construction
99	416	Database- directory- and other publishers
100	473	Independent artists- writers- and performers
101	497	State and local government passenger transit
102	453	Facilities support services
103	456	Travel arrangement and reservation services
104	443	Other computer related services
105	445	Environmental and other technical consulting
106	432	Automotive equipment rental and leasing
107	452	Office administrative services
108	418	Motion picture and video industries
109	440	Specialized design services
110	420	Radio and television broadcasting
111	67	Animal- except poultry- slaughtering
112	311	Semiconductors and related device manufacturing
113	37	Manufacturing and industrial buildings
114	485	Commercial machinery repair and maintenance
115	375	Surgical and medical instrument manufacturing
116	243	Machine shops
117	482	Car washes
118	312	All other electronic component manufacturing
119	42	Maintenance and repair of farm and nonfarm
120	86	Breweries
121	27	Drilling oil and gas wells
122	414	Periodical publishers
123	392	Rail transportation
124	10	All other crop farming
125	314	Search- detection- and navigation instruments
126	421	Cable networks and program distribution
127	73	Bread and bakery product
128	305	Other computer peripheral equipment manufacturing
129	484	Electronic equipment repair and maintenance
130	160	Pharmaceutical and medicine manufacturing
131	177	Plastics plumbing fixtures and all other
132	362	Wood kitchen cabinet and countertop manufacturing
133	433	Video tape and disc rental
134	480	Other accommodations

Ranking	Industry Code	Description
135	192	Ready-mix concrete manufacturing
136	20	Coal mining
137	434	Machinery and equipment rental and leasing
138	44	Maintenance and repair of highways- streets-
139	448	Photographic services
140	486	Household goods repair and maintenance
141	475	Museums- historical sites- zoos- and parks
142	303	Computer storage device manufacturing
143	6	Greenhouse and nursery production
144	85	Soft drink and ice manufacturing
145	488	Death care services
146	170	Photographic film and chemical manufacturing
147	318	Electricity and signal testing instruments
148	498	State and local government electric utilities
149	116	Engineered wood member and truss manufacturing
150	384	Sign manufacturing
151	423	Information services
152	477	Bowling centers
153	313	Electro-medical apparatus manufacturing
154	126	Paperboard container manufacturing
155	306	Telephone apparatus manufacturing
156	68	Meat processed from carcasses
157	107	Cut and sew apparel manufacturing
158	376	Surgical appliance and supplies manufacturing
159	31	Natural gas distribution
160	195	Other concrete product manufacturing
161	415	Book publishers
162	233	Fabricated structural metal manufacturing
163	23	Gold- silver- and other metal ore mining
164	350	Motor vehicle parts manufacturing
165	3	Vegetable and melon farming
166	117	Wood windows and door manufacturing
167	286	Other engine equipment manufacturing
168	373	Blind and shade manufacturing
169	62	Fluid milk manufacturing
170	278	AC- refrigeration- and forced air heating
171	25	Sand- gravel- clay- and refractory mining
172	58	Confectionery manufacturing from purchased
173	236	Sheet metal work manufacturing
174	184	Porcelain electrical supply manufacturing
175	302	Electronic computer manufacturing
176	203	Iron and steel mills
177	240	Metal can- box- and other container manufacturing
178	381	Sporting and athletic goods manufacturing
179	316	Industrial process variable instruments

Ranking	Industry Code	Description
180	14	Logging
181	351	Aircraft manufacturing
182	273	Other commercial and service industry machine
183	319	Analytical laboratory instrument manufacturing
184	379	Dental laboratories
185	101	Textile bag and canvas mills
186	32	Water- sewage and other systems
187	372	Mattress manufacturing
188	436	Lesser of nonfinancial intangible assets
189	371	Showcases- partitions- shelving- and lockers
190	202	Miscellaneous nonmetallic mineral products
191	364	Non-upholstered wood household furniture
192	248	Metal valve manufacturing
193	179	Tire manufacturing
194	70	Poultry processing
195	24	Stone mining and quarrying
196	241	Hardware manufacturing
197	396	Pipeline transportation
198	84	All other food manufacturing
199	9	Sugarcane and sugar beet farming
200	189	Glass container manufacturing
201	193	Concrete block and brick manufacturing
202	103	Other miscellaneous textile product mills
203	119	Other millwork- including flooring
204	257	Farm machinery and equipment manufacturing
205	237	Ornamental and architectural metal work
206	246	Metal coating and non-precious engraving
207	244	Turned product and screw- nut- and bolt
208	173	Plastics pipe- fittings- and profile shapes
209	271	Optical instrument and lens manufacturing
210	64	Cheese manufacturing
211	322	Software reproducing
212	292	Conveyor and conveying equipment manufacturing
213	120	Wood container and pallet manufacturing
214	77	Tortilla manufacturing
215	353	Other aircraft parts and equipment
216	122	Prefabricated wood building manufacturing
217	383	Office supplies- except paper- manufacturing
218	121	Manufactured home- mobile home- manufacturing
219	178	Foam product manufacturing
220	199	Cut stone and stone product manufacturing
221	308	Other communications equipment manufacturing
222	79	Other snack food manufacturing
223	234	Plate work manufacturing
224	47	Other animal food manufacturing

Ranking	Industry Code	Description
225	185	Brick and structural clay tile manufacturing
226	369	Custom architectural woodwork and millwork
227	255	Miscellaneous fabricated metal product
228	389	Buttons- pins- and all other miscellaneous
229	229	Hand and edge tool manufacturing
230	247	Electroplating- anodizing- and coloring metal
231	321	Watch- clock- and other measuring and control
232	366	Institutional furniture manufacturing
233	242	Spring and wire product manufacturing
234	190	Glass and glass products- except glass
235	80	Coffee and tea manufacturing
236	235	Metal window and door manufacturing
237	113	Wood preservation
238	46	Dog and cat food manufacturing
239	300	Fluid power pump and motor manufacturing
240	267	Food product machinery manufacturing
241	142	Petroleum refineries
242	307	Broadcast and wireless communications
243	349	Travel trailer and camper manufacturing
244	279	Industrial mold manufacturing
245	112	Sawmills
246	326	Lighting fixture manufacturing
247	194	Concrete pipe manufacturing
248	227	All other forging and stamping
249	123	Miscellaneous wood product manufacturing
250	377	Dental equipment and supplies manufacturing
251	172	Plastics packaging materials- film and sheet
252	171	Other miscellaneous chemical product manufacturing
253	61	Fruit and vegetable canning and drying
254	29	Support activities for other mining
255	276	Industrial and commercial fan and blower
256	239	Metal tank- heavy gauge- manufacturing
257	254	Enameled iron and metal sanitary ware
258	100	Curtain and linen mills
259	12	Poultry and egg production
260	75	Mixes and dough made from purchased flour
261	281	Metal forming machine tool manufacturing
262	108	Accessories and other apparel manufacturing
263	232	Prefabricated metal buildings and components
264	56	Sugar manufacturing
265	385	Gasket- packing- and sealing device
266	174	Laminated plastics plate- sheet- and shapes
267	343	Miscellaneous electrical equipment
268	352	Aircraft engine and engine parts
269	294	Industrial truck- trailer- and stacker

Ranking	Industry Code	Description
270	347	Truck trailer manufacturing
271	382	Doll- toy- and game manufacturing
272	380	Jewelry and silverware manufacturing
273	150	Other basic inorganic chemical manufacturing
274	164	Polish and other sanitation good
275	419	Sound recording industries
276	191	Cement manufacturing
277	118	Cut stock- re-sawing lumber
278	284	Rolling mill and other metalworking machinery
279	334	Motor and generator manufacturing
280	317	Totalizing fluid meters and counting devices
281	148	Industrial gas manufacturing
282	26	Other nonmetallic mineral mining
283	337	Storage battery manufacturing
284	162	Adhesive manufacturing
285	140	Trade-binding and related work
286	1	Oilseed farming
287	252	Fabricated pipe and pipe fitting
288	346	Motor vehicle body manufacturing
289	5	Fruit farming
290	143	Asphalt paving mixture and block
291	222	Aluminum foundries
292	301	Scales- balances- and miscellaneous general p
293	327	Electric housewares and household fan
294	161	Paint and coating manufacturing
295	336	Relay and industrial control manufacturing
296	282	Special tool- die- jig- and fixture
297	166	Toilet preparation manufacturing
298	66	Ice cream and frozen dessert manufacturing
299	110	Footwear manufacturing
300	129	Coated and laminated paper and packaging mate
301	83	Spice and extract manufacturing
302	197	Gypsum product manufacturing
303	138	Blankbook and loose-leaf binder manufacturing
304	181	Other rubber product manufacturing
305	269	All other industrial machinery manufacturing
306	60	Frozen food manufacturing
307	111	Other leather product manufacturing
308	374	Laboratory apparatus and furniture
309	309	Audio and video equipment manufacturing
310	211	Aluminum sheet- plate- and foil manufacturing
311	259	Construction machinery manufacturing
312	223	Nonferrous foundries- except aluminum
313	97	Textile and fabric finishing mills
314	261	Oil and gas field machinery and equipment

Ranking	Industry Code	Description
315	205	Iron- steel pipe and tube from purchased
316	356	Railroad rolling stock manufacturing
317	141	Prepress services
318	175	Plastics bottle manufacturing
319	217	Copper wire- except mechanical- drawing
320	144	Asphalt shingle and coating materials
321	328	Household vacuum cleaner manufacturing
322	132	Envelope manufacturing
323	226	Custom roll forming
324	151	Other basic organic chemical manufacturing
325	87	Wineries
326	158	Fertilizer- mixing only- manufacturing
327	266	Printing machinery and equipment
328	370	Office furniture- except wood- manufacturing
329	339	Fiber optic cable manufacturing
330	48	Flour milling
331	145	Petroleum lubricating oil and grease
332	323	Audio and video media reproduction
333	16	Fishing
334	224	Iron and steel forging
335	265	Textile machinery manufacturing
336	207	Steel wire drawing
337	17	Hunting and trapping
338	272	Photographic and photocopying equipment
339	359	Motorcycle- bicycle- and parts manufacturing
340	335	Switchgear and switchboard apparatus
341	169	Custom compounding of purchased resins
342	341	Wiring device manufacturing
343	275	Air purification equipment manufacturing
344	283	Cutting tool and machine tool accessory
345	152	Plastics material and resin manufacturing
346	135	All other converted paper product
347	296	Welding and soldering equipment manufacturing
348	163	Soap and other detergent manufacturing
349	333	Electric power and specialty transformer
350	183	Vitreous china and earthenware articles
351	378	Ophthalmic goods manufacturing
352	325	Electric lamp bulb and part manufacturing
353	136	Manifold business forms printing
354	256	Ammunition manufacturing
355	115	Veneer and plywood manufacturing
356	57	Confectionery manufacturing from cacao beans
357	74	Cookie and cracker manufacturing
358	368	Wood office furniture manufacturing
359	260	Mining machinery and equipment manufacturing

Ranking	Industry Code	Description
360	345	Heavy duty truck manufacturing
361	386	Musical instrument manufacturing
362	201	Mineral wool manufacturing
363	137	Books printing
364	59	Non-chocolate confectionery manufacturing
365	289	Air and gas compressor manufacturing
366	268	Semiconductor machinery manufacturing
367	270	Office machinery manufacturing
368	99	Carpet and rug mills
369	71	Seafood product preparation and packaging
370	82	Mayonnaise- dressing- and sauce manufacturing
371	200	Ground or treated minerals and earths
372	253	Industrial pattern manufacturing
373	221	Ferrous metal foundries
374	297	Packaging machinery manufacturing
375	340	Other communication and energy wire
376	315	Automatic environmental control manufacturing
377	165	Surface active agent manufacturing
378	188	Clay refractory and other structural clay
379	109	Leather and hide tanning and finishing
380	338	Primary battery manufacturing
381	69	Rendering and meat byproduct processing
382	367	Other household and institutional furniture
383	131	Die-cut paper office supplies manufacturing
384	263	Plastics and rubber industry machinery
385	167	Printing ink manufacturing
386	228	Cutlery and flatware- except precious-
387	288	Pump and pumping equipment manufacturing
388	245	Metal heat treating
389	15	Forest nurseries- forest products- and timber
390	114	Reconstituted wood product manufacturing
391	264	Paper industry machinery manufacturing
392	363	Upholstered household furniture manufacturing
393	277	Heating equipment- except warm air furnaces
394	215	Primary nonferrous metal- except copper
395	206	Rolled steel shape manufacturing
396	212	Aluminum extruded product manufacturing
397	54	Fats and oils refining and blending
398	106	Other apparel knitting mills
399	320	Irradiation apparatus manufacturing
400	387	Broom- brush- and mop manufacturing
401	361	All other transportation equipment
402	76	Dry pasta manufacturing
403	186	Ceramic wall and floor tile manufacturing
404	180	Rubber and plastics hose and belting

Ranking	Industry Code	Description
405	365	Metal household furniture manufacturing
406	358	Boat building
407	134	Sanitary paper product manufacturing
408	299	Fluid power cylinder and actuator
409	213	Other aluminum rolling and drawing
410	393	Water transportation
411	105	Other hosiery and sock mills
412	94	Narrow fabric mills and embroidery
413	159	Pesticide and other agricultural chemical man
414	22	Copper- nickel- lead- and zinc mining
415	51	Wet corn milling
416	127	Flexible packaging foil manufacturing
417	238	Power boiler and heat exchanger manufacturing
418	198	Abrasive product manufacturing
419	310	Electron tube manufacturing
420	225	Nonferrous forging
421	168	Explosives manufacturing
422	65	Dry- condensed- and evaporated dairy products
423	324	Magnetic and optical recording media
424	133	Stationery and related product manufacturing
425	219	Nonferrous metal- except copper and aluminum
426	280	Metal cutting machine tool manufacturing
427	251	Other ordnance and accessories manufacturing
428	293	Overhead cranes- hoists- and monorail systems
429	88	Distilleries
430	98	Fabric coating mills
431	262	Sawmill and woodworking machinery
432	285	Turbine and turbine generator set units
433	298	Industrial process furnace and oven
434	287	Speed changers and mechanical power
435	55	Breakfast cereal manufacturing
436	344	Automobile and light truck manufacturing
437	176	Resilient floor covering manufacturing
438	258	Lawn and garden equipment manufacturing
439	78	Roasted nuts and peanut butter manufacturing
440	72	Frozen cakes and other pastries manufacturing
441	249	Ball and roller bearing manufacturing
442	125	Paper and paperboard mills
443	342	Carbon and graphite product manufacturing
444	250	Small arms manufacturing
445	156	Nitrogenous fertilizer manufacturing
446	274	Automatic vending- commercial laundry and dry
447	388	Burial casket manufacturing
448	93	Broad-woven fabric mills
449	182	Vitreous china plumbing fixture manufacturing

Ranking	Industry Code	Description
450	63	Creamery butter manufacturing
451	355	Propulsion units and parts for space vehicles
452	*4*	*Tree nut farming*
453	*7*	*Tobacco farming*
454	*8*	*Cotton farming*
455	*21*	*Iron ore mining*
456	*36*	*New farm housing units*
457	*49*	*Rice milling*
458	*50*	*Malt manufacturing*
459	*52*	*Soybean processing*
460	*53*	*Other oilseed processing*
461	*81*	*Flavoring syrup and concentrate manufacturing*
462	*89*	*Tobacco stemming and re-drying*
463	*90*	*Cigarette manufacturing*
464	*91*	*Other tobacco product manufacturing*
465	*92*	*Fiber- yarn- and thread mills*
466	*95*	*Nonwoven fabric mills*
467	*96*	*Knit fabric mills*
468	*102*	*Tire cord and tire fabric mills*
469	*104*	*Sheer hosiery mills*
470	*124*	*Pulp mills*
471	*128*	*Surface-coated paperboard manufacturing*
472	*130*	*Coated and uncoated paper bag manufacturing*
473	*146*	*All other petroleum and coal products*
474	*147*	*Petrochemical manufacturing*
475	*149*	*Synthetic dye and pigment manufacturing*
476	*153*	*Synthetic rubber manufacturing*
477	*154*	*Cellulosic organic fiber manufacturing*
478	*155*	*Non-cellulosic organic fiber manufacturing*
479	*157*	*Phosphoric fertilizer manufacturing*
480	*187*	*Non-clay refractory manufacturing*
481	*196*	*Lime manufacturing*
482	*204*	*Ferroalloy and related product manufacturing*
483	*208*	*Alumina refining*
484	*209*	*Primary aluminum production*
485	*210*	*Secondary smelting and alloying of aluminum*
486	*214*	*Primary smelting and refining of copper*
487	*216*	*Copper rolling- drawing- and extruding*
488	*218*	*Secondary processing of copper*
489	*220*	*Secondary processing of other nonferrous*
490	*230*	*Saw blade and handsaw manufacturing*
491	*231*	*Kitchen utensil- pot- and pan manufacturing*
492	*290*	*Measuring and dispensing pump manufacturing*
493	*291*	*Elevator and moving stairway manufacturing*
494	*295*	*Power-driven handtool manufacturing*

Ranking	Industry Code	Description
495	*304*	*Computer terminal manufacturing*
496	*329*	*Household cooking appliance manufacturing*
497	*330*	*Household refrigerator and home freezer*
498	*331*	*Household laundry equipment manufacturing*
499	*332*	*Other major household appliance manufacturing*
500	*348*	*Motor home manufacturing*
501	*357*	*Ship building and repairing*
502	*360*	*Military armored vehicles and tank parts*
503	*495*	*Federal electric utilities*
504	*500*	*Non-comparable imports*
505	*501*	*Scrap*
506	*502*	*Used and secondhand goods*
507	*507*	*Rest of the world adjustment to final uses*
508	*508*	*Inventory valuation adjustment*
509	*509*	*Owner-occupied dwellings*

**From the 452th sector on, employments are zero since sectors do not exist in Colorado*

Appendix 3.2 Full commodity balance sheet for sector 32 (water supply)

Ranking of Colorado's industries by gross input from sector 32

Ranking	Industry Code	Description
1	431	Real estate
2	499	Other State and local government enterprises
3	422	Telecommunications
4	498	State and local government electric utilities
5	479	Hotels and motels- including casino hotels
6	451	Management of companies and enterprises
7	481	Food services and drinking places
8	425	Nondepository credit intermediation
9	11	Cattle ranching and farming
10	390	Wholesale trade
11	450	All other miscellaneous professional and technical
12	467	Hospitals
13	478	Other amusement- gambling- and recreation
14	33	New residential 1-unit structures- all
15	460	Waste management and remediation services
16	491	Religious organizations
17	19	Oil and gas extraction
18	203	Iron and steel mills
19	27	Drilling oil and gas wells
20	456	Travel arrangement and reservation services
21	446	Scientific research and development services
22	468	Nursing and residential care facilities
23	421	Cable networks and program distribution
24	439	Architectural and engineering services
25	10	All other crop farming
26	426	Securities- commodity contracts- investments
27	466	Other ambulatory health care services
28	459	Other support services
29	465	Offices of physicians- dentists- and other health
30	401	Motor vehicle and parts dealers
31	480	Other accommodations
32	405	Food and beverage stores
33	2	Grain farming
34	410	General merchandise stores

Ranking	Industry Code	Description
35	38	Commercial and institutional buildings
36	489	Dry-cleaning and laundry services
37	398	Postal service
38	404	Building material and garden supply stores
39	496	Other Federal Government enterprises
40	483	Automotive repair and maintenance- except car wash
41	470	Social assistance- except child day care services
42	493	Civic- social- professional and similar
43	458	Services to buildings and dwellings
44	469	Child day care services
45	455	Business support services
46	85	Soft drink and ice manufacturing
47	430	Monetary authorities and depository credit
48	3	Vegetable and melon farming
49	476	Fitness and recreational sports centers
50	482	Car washes
51	408	Clothing and clothing accessories stores
52	434	Machinery and equipment rental and leasing
53	412	Non-store retailers
54	43	Maintenance and repair of nonresidential buildings
55	490	Other personal services
56	402	Furniture and home furnishings stores
57	437	Legal services
58	438	Accounting and bookkeeping services
59	487	Personal care services
60	13	Animal production- except cattle and poultry
61	417	Software publishers
62	30	Power generation and supply
63	440	Specialized design services
64	444	Management consulting services
65	409	Sporting goods- hobby- book and music stores
66	407	Gasoline stations
67	463	Other educational services
68	406	Health and personal care stores
69	445	Environmental and other technical consulting
70	394	Truck transportation
71	477	Bowling centers
72	416	Database- directory- and other publishers

Ranking	Industry Code	Description
73	41	Other new construction
74	428	Insurance agencies- brokerages- and related
75	424	Data processing services
76	35	New residential additions and alterations- all
77	400	Warehousing and storage
78	447	Advertising and related services
79	411	Miscellaneous store retailers
80	391	Air transportation
81	472	Spectator sports
82	150	Other basic inorganic chemical manufacturing
83	452	Office administrative services
84	418	Motion picture and video industries
85	475	Museums- historical sites- zoos- and parks
86	435	General and consumer goods rental except video tape
87	432	Automotive equipment rental and leasing
88	42	Maintenance and repair of farm and nonfarm
89	9	Sugarcane and sugar beet farming
90	488	Death care services
91	453	Facilities support services
92	395	Transit and ground passenger transportation
93	461	Elementary and secondary schools
94	12	Poultry and egg production
95	39	Highway- street- bridge- and tunnel construction
96	34	New multifamily housing structures- all
97	413	Newspaper publishers
98	485	Commercial machinery repair and maintenance
99	442	Computer systems design services
100	420	Radio and television broadcasting
101	492	Grantmaking and giving and social advocacy
102	40	Water- sewer- and pipeline construction
103	464	Home health care services
104	486	Household goods repair and maintenance
105	31	Natural gas distribution
106	497	State and local government passenger transit
107	471	Performing arts companies
108	484	Electronic equipment repair and maintenance
109	45	Other maintenance and repair construction
110	403	Electronics and appliance stores

Ranking	Industry Code	Description
111	397	Scenic and sightseeing transportation and support
112	449	Veterinary services
113	392	Rail transportation
114	423	Information services
115	86	Breweries
116	6	Greenhouse and nursery production
117	448	Photographic services
118	473	Independent artists- writers- and performers
119	399	Couriers and messengers
120	433	Video tape and disc rental
121	462	Colleges- universities- and junior colleges
122	414	Periodical publishers
123	457	Investigation and security services
124	1	Oilseed farming
125	37	Manufacturing and industrial buildings
126	25	Sand- gravel- clay- and refractory mining
127	142	Petroleum refineries
128	474	Promoters of performing arts and sports and agents
129	5	Fruit farming
130	20	Coal mining
131	160	Pharmaceutical and medicine manufacturing
132	454	Employment services
133	24	Stone mining and quarrying
134	415	Book publishers
135	441	Custom computer programming services
136	311	Semiconductors and related device manufacturing
137	148	Industrial gas manufacturing
138	302	Electronic computer manufacturing
139	28	Support activities for oil and gas operations
140	443	Other computer related services- including
141	44	Maintenance and repair of highways- streets-
142	56	Sugar manufacturing
143	303	Computer storage device manufacturing
144	351	Aircraft manufacturing
145	419	Sound recording industries
146	191	Cement manufacturing
147	151	Other basic organic chemical manufacturing
148	286	Other engine equipment manufacturing

Ranking	Industry Code	Description
149	273	Other commercial and service industry machinery
150	79	Other snack food manufacturing
151	68	Meat processed from carcasses
152	58	Confectionery manufacturing
153	67	Animal- except poultry- slaughtering
154	17	Hunting and trapping
155	15	Forest nurseries- forest products
156	305	Other computer peripheral equipment manufacturing
157	375	Surgical and medical instrument manufacturing
158	171	Other miscellaneous chemical product manufacturing
159	343	Miscellaneous electrical equipment manufacturing
160	62	Fluid milk manufacturing
161	117	Wood windows and door manufacturing
162	84	All other food manufacturing
163	73	Bread and bakery product- except frozen-
164	113	Wood preservation
165	237	Ornamental and architectural metal work
166	189	Glass container manufacturing
167	61	Fruit and vegetable canning and drying
168	179	Tire manufacturing
169	143	Asphalt paving mixture and block manufacturing
170	152	Plastics material and resin manufacturing
171	64	Cheese manufacturing
172	197	Gypsum product manufacturing
173	257	Farm machinery and equipment manufacturing
174	429	Funds- trusts- and other financial vehicles
175	314	Search- detection- and navigation instruments
176	241	Hardware manufacturing
177	192	Ready-mix concrete manufacturing
178	362	Wood kitchen cabinet and countertop manufacturing
179	164	Polish and other sanitation good manufacturing
180	240	Metal can- box- and other container manufacturing
181	165	Surface active agent manufacturing
182	112	Sawmills
183	350	Motor vehicle parts manufacturing
184	80	Coffee and tea manufacturing
185	162	Adhesive manufacturing
186	177	Plastics plumbing fixtures and all other plastics

Ranking	Industry Code	Description
187	211	Aluminum sheet- plate- and foil manufacturing
188	119	Other millwork- including flooring
189	51	Wet corn milling
190	122	Prefabricated wood building manufacturing
191	393	Water transportation
192	353	Other aircraft parts and equipment
193	233	Fabricated structural metal manufacturing
194	69	Rendering and meat byproduct processing
195	60	Frozen food manufacturing
196	200	Ground or treated minerals and earths manufacturing
197	205	Iron- steel pipe and tube from purchased steel
198	190	Glass and glass products- except glass containers
199	47	Other animal food manufacturing
200	163	Soap and other detergent manufacturing
201	54	Fats and oils refining and blending
202	278	AC- refrigeration- and forced air heating
203	103	Other miscellaneous textile product mills
204	213	Other aluminum rolling and drawing
205	232	Prefabricated metal buildings and components
206	158	Fertilizer- mixing only- manufacturing
207	325	Electric lamp bulb and part manufacturing
208	247	Electroplating- anodizing- and coloring metal
209	120	Wood container and pallet manufacturing
210	135	All other converted paper product manufacturing
211	97	Textile and fabric finishing mills
212	246	Metal coating and non-precious engraving
213	144	Asphalt shingle and coating materials manufacturing
214	126	Paperboard container manufacturing
215	186	Ceramic wall and floor tile manufacturing
216	242	Spring and wire product manufacturing
217	178	Foam product manufacturing
218	279	Industrial mold manufacturing
219	123	Miscellaneous wood product manufacturing
220	118	Cut stock- res-awing lumber
221	129	Coated and laminated paper and packaging materials
222	109	Leather and hide tanning and finishing
223	364	Non-upholstered wood household furniture
224	139	Commercial printing

Ranking	Industry Code	Description
225	99	Carpet and rug mills
226	159	Pesticide and other agricultural chemical manufacturing
227	59	Non-chocolate confectionery manufacturing
228	161	Paint and coating manufacturing
229	356	Railroad rolling stock manufacturing
230	201	Mineral wool manufacturing
231	114	Reconstituted wood product manufacturing
232	334	Motor and generator manufacturing
233	224	Iron and steel forging
234	259	Construction machinery manufacturing
235	181	Other rubber product manufacturing
236	215	Primary nonferrous metal- except copper
237	336	Relay and industrial control manufacturing
238	221	Ferrous metal foundries
239	172	Plastics packaging materials- film and sheet
240	282	Special tool- die- jig- and fixture manufacturing
241	283	Cutting tool and machine tool accessory manufacturing
242	156	Nitrogenous fertilizer manufacturing
243	136	Manifold business forms printing
244	206	Rolled steel shape manufacturing
245	125	Paper and paperboard mills
246	365	Metal household furniture manufacturing
247	65	Dry- condensed- and evaporated dairy products
248	180	Rubber and plastics hose and belting manufacturing
249	115	Veneer and plywood manufacturing
250	212	Aluminum extruded product manufacturing
251	106	Other apparel knitting mills
252	98	Fabric coating mills
253	88	Distilleries
254	363	Upholstered household furniture manufacturing
255	285	Turbine and turbine generator set units manufacturing
256	55	Breakfast cereal manufacturing
257	219	Nonferrous metal- except copper and aluminum
258	78	Roasted nuts and peanut butter manufacturing
259	344	Automobile and light truck manufacturing
260	93	Broad woven fabric mills

Appendix 3.3 Photographs of low reservoir levels at Crawford and Ridgway