Proposal for Joint USGS/BLM Study of Water-Quality and Biological Impacts of Forest Fertilization, Little River Adaptive Management Area, Oregon

by Chauncey Anderson, U.S. Geological Survey – Water Resources Division
Oregon District

1.0 Summary

This proposal is for a study in which the USGS will assist the Bureau of Land Management in Roseburg, Oregon, in determining effects of forest fertilization with urea on water quality and aquatic biological communities. In FY98 and 99 the USGS conducted a review of literature on forest fertilizations and on fate and transport of nitrogen in streams, and conducted reconnaissance water quality samplings, as an initial phase of the project. Fertilization will be done in

2.0 Problem

Fertilization of public and private timber lands with nitrogen to boost forest productivity has been a common practice in the Pacific Northwest and elsewhere, beginning in the late 1960's (Frederiksen, 1975; NCASI, 1999), and the possibility of negative impacts on stream-water quality from loss of fertilizer nitrogen has long been recognized (Cole and Gessel, 1965). Forest fertilizer losses to streams and their impacts on water quality have been studied numerous times, and these studies have been periodically reviewed (Moore, 1975; Frederiksen and others, 1975; Bisson and others, 1992; Binkley and Brown, 1993; NCASI, 1999). In all reported studies there have been losses of nitrogen to streams from fertilizer applications, the magnitudes of which are variable and range from less than 1% (Frederiksen, 1975) of applied nitrogen to greater than 25% (Edwards and others, 1991). The amount of fertilizer lost to streams depends on many factors, including the amount and type of fertilizer applied, the timing of application, hydrologic conditions during and after applications, the types of trees and other vegetation in the watershed, the geochemistry of soils of the individual forests, the degree of recent disturbance of the watershed in which the fertilizer was applied, the frequency of previous fertilizations and other nitrogen deposition history, and the width and effectiveness of unfertilized riparian buffer zones around streams. The degree to which these factors interact remains unclear.

Despite losses of applied fertilizer nitrogen, rarely have any violations of water-quality criteria, including criteria for ammonia toxicity and for nitrate nitrogen in drinking water, been reported to result from forest fertilizations. However, investigations of biological effects of the added nitrogen, though usually recommended, have been few. This proposal outlines a project by the U. S. Geological Survey to evaluate the impacts of an operational forest fertilization by the Roseburg, Oregon office of the Bureau of Land Management (BLM). Urea nitrogen will be applied to individual forested stands of the nitrogen-limited Little River Basin (fig.1), a tributary to the North Umpqua River, during late-fall 2000. The study will include examination of both water quality and possible ecological effects of added fertilizer nitrogen; these effects include eutrophication of streams by increased biomass of periphytic algae, impacts of increased algal growth and primary production on dissolved oxygen and pH in streams, changes in algal species community composition, and changes in secondary grazer (macroinvertebrate) communities or food web structure and functioning that might accompany changes in algal community composition and biomass. The USGS has already completed several reconnaissance samplings and review of forest fertilization literature (see table 2) for the BLM during FY98 and FY99, so this proposal reflects the continuation of an ongoing program.

Previous studies in the Umpqua Basin have indicated that several streams, including the South Umpqua River (Tanner and Anderson, 1996), North Umpqua River, and Little River (Powell, 1995, 1998; Anderson and Carpenter, 1998) experience nuisance growths of attached algae during summer low flow periods. In many locations photosynthetic processes from the large amounts of algae have resulted in pH values higher than the State of Oregon Standard of 8.5, with maximum values in the Little River Basin reaching as high as 9.1 (Anderson and Carpenter, 1998; Powell, 1995, 1998). The Little River is listed on the State of Oregon’s 303(d) list of water-quality limited streams for pH, temperature,

Figure 1. Map showing location of the Little River Basin and the larger North Umpqua Basin, Oregon

sedimentation, and habitat modification (Oregon Department of Environmental Quality, 1999). Longitudinal surveys in various streams in the Little River Basin have shown general increases in pH in a downstream direction, and there are substantial diel variations in pH and dissolved oxygen (Powell, 1995, 1998) that are characteristic of changes induced by primary production (fig 2). Powell (1997) related daily maximum pH to the areal extent of historical logging upstream from the sampling location; mechanisms that have been proposed to account for nuisance algal growth and / or elevated pH in forested areas include excessive nutrient inputs from erosional and other processes associated with timber operations and reduced benthic respiration due to reduced hyporheic area available for heterotrophic metabolism (Powell, 1996; Anderson and Carpenter, 1998).

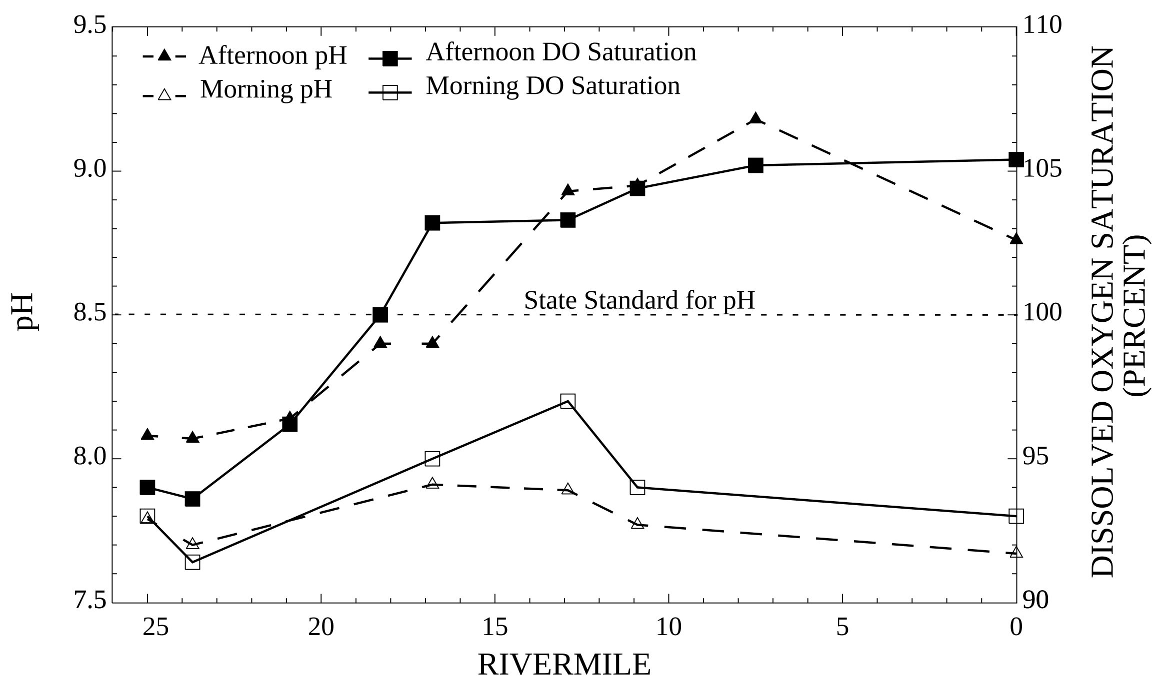

Figure 2. Morning and afternoon pH and dissolved oxygen (DO) saturation in the Little River, July 28, 1998. Source: Powell, 1998.

Problems with water-quality and ecosystem processes in the Little River Basin are evident beyond just exceedances of state water-quality standards. Aquatic species of concern in the Little River include the Umpqua River cutthroat trout, the

Oregon Coast coho salmon, the Oregon Coast steelhead trout, the Pacific lamprey, the tailed frog, and the red-legged frog (table 1)(John Raby, Bureau of Land Management, written commun., August 1999; Dr. Bruce Bury, U. S. Geological Survey, written commun., August 1999). These species could potentially be affected if food chains upon which they are dependant are disrupted at their base (that is, at the level of primary production) through inputs of critical nutrients. To the extent that management activities on forest lands in the basin affects these and other species, public lands agencies are mandated to strive to balance those activities with the needs of the aquatic biota. Thus it is important to understand the potential or real impacts on aquatic communities from activities such as forest fertilization.

Table 1. Aquatic species of concern in the Little River Basin, Oregon

Species	Federal Designation	State of Oregon Designation
Umpqua River cutthroat trout	Endangered	Sensitive/Vulnerable
Oregon Coast coho salmon	Threatened	Sensitive/Critical
Oregon Coast steelhead trout	Candidate	Sensitive/Vulnerable
Pacific Lamprey	Species of Concern	Sensitive/Vulnerable
Red Legged Frog	Sensitive[a]	--

a. listed on the National Forest Sensitive Species List

Forestry is by far the dominant land use in the Little River Basin. Roughly 60 percent of the drainage area of the basin had been harvested for timber and reforested by 1995 (U.S.D.A. Forest Service and Bureau of Land Management, 1995). In 1994 the public land in the watershed was collectively designated as one of ten Adaptive Management Areas (AMAs) under the President’s Northwest Forest Plan (U.S.D.A. Forest Service and Bureau of Land Management, 1994); the specific emphasis of the Little River Adaptive Management Area (LRAMA) is “the development and testing of approaches to integration of intensive timber production with restoration and maintenance of high quality riparian habitat” (U.S.D.A. Forest Service and Bureau of Land Management, 1995). As such, the

LRAMA is the only AMA in which evaluation of the effects of forest management on water quality is officially designated as an objective.

Timber operations are known to contribute nutrients to streams from a variety of processes including sediment erosion, clearcutting operations, burning, and fertilization (Frederiksen and others, 1971; Tamm and others, 1974; Sollins and McCorison, 1981; Tiedman and others, 1988; Adams and Stack, 1989; Norris and others, 1991; Binkley and Brown, 1993; NCASI, 1999). These processes were among the nutrient sources considered a recent project in the larger North Umpqua River Basin, where similar issues of nutrients, benthic algal growth, and high pH were evaluated by the USGS in conjunction with timber and hydropower operations (Anderson and Carpenter, 1998). On the basis of findings of apparent nitrogen limitation in streams of the North Umpqua River Basin the Roseburg District of the Umpqua National Forest suspended forest fertilization practices in the forest until more could be learned about its effects on water quality.

A confounding aspect to this study is the patchwork pattern of land ownership in the basin (fig. 1). Private timber lands are intermixed in alternating square mile Sections with BLM and Forest Service lands in the middle portions of the LRAMA, in particuluar in the Wolf and Cavitt Creek watersheds. In the fall of 1998, private timber lands in the Cavitt Creek, Wolf Creek, and Negro Creek drainages were fertilized by the landowner with little advance notice to BLM or USGS. Initial reports were that all of the private timber lands in these basins were being fertilized, as opposed to discreet stands as the BLM is planning to do, so relatively large areas were fertilized; confirmation of actual private fertilization areas and amounts, and other information on land use history in private lands, have yet to be received. Furthermore, the private timber companies are required to conform to the State of Oregon Forest Practices Rules and Forest Practices Act (Oregon Administrative Rules 629-620-400), which requires no buffer strips for streams such as those in the Little River Basin, and prohibits application directly to large and medium sized streams but not to smaller streams such as the tributaries to Wolf and Negro Creek. Fertilizations on federal forest lands must maintain 100 foot buffer strips around all streams. Buffer strips have been shown in several studies to reduce the magnitude of short term pulses of urea and ammonium following fertilization and to reduce the overall losses of nitrate (Cline, 1973; Stay and others, 1979; NCASI, 1999). For these reasons, care will be needed to differentiate impacts to medium to large scale streams in the LRAMA resulting from fertilization by BLM from impacts resulting from other land uses, thus driving the need to include smaller scale research at reach and subbasin scales to minimize confounding effects from upstream.

3.0 Objectives for Fertilization Study

In keeping with its mission under the President's Northwest Forest Plan (U.S.D.A. Forest Service and Bureau of Land Management, 1994), the BLM is interested in studying the effects of forest fertilization with urea-nitrogen on water quality and stream ecology in the Little River Adaptive Management Area. Fertilization with urea-nitrogen is planned at 200 pounds N / acre (224 kg N/ha), with 100 foot buffer strips, and will be applied to various 15-40 year old stands of Douglas-fir trees. Specifically, the objectives of the study are to determine:

- effects of fertilizer nutrients inputs on the aquatic ecosystem, including algae and potentially higher trophic levels, such as invertebrate and/or fish communities,
- interactions in the Little River Basin between nutrient inputs, aquatic ecosystems, and water quality, particularly pH and dissolved oxygen, and
- downstream cumulative impacts, both spatially and temporally, of forest fertilization on water quality and aquatic systems.

4.0 Benefits

This study will have numerous potential benefits that are consistent with both the mission of the BLM in managing Adaptive Management Areas and the USGS' strategic plan (U. S. Geological Survey, 1999). Benefits will include (1) filling important needs for approaching and understanding environmental effects of forest land-management, (2) advancing scientific understanding of linkages between forest uplands and stream ecosystems, and(or) within different compartments of stream ecosystems, and (3) fostering partnerships and coordination between land management agencies and sister agencies within the Department of Interior, and academic institutions.

From a land management standpoint, the impacts of forest management on stream ecosystems is one of the most visible environmental issues in the Pacific Northwest. The President's Northwest Forest Plan (U.S.D.A. Forest Service and Bureau of Land Management, 1994) was a result of divisiveness around this issue, and the creation of Adaptive Management Areas such as the LRAMA was one mechanism established to help strike a balance between the use and protection of natural resources in forested areas. The stakes are high in areas such as Douglas County and the Little River Basin, where timber related jobs are a large part of the local economy but where the integrity of natural systems (including threatened or endangered species) are highly valued.

Successful completion of this study will benefit the Bureau of Land Management as well as other agencies charged with managing timber land, including the USDA Forest Service and Oregon Department of Forestry, by helping to clarify the impacts that fertilization has on stream ecosystems. Because fertilization of forests with nitrogen is such a common practice (though often unknown to the public), it is important to know more about its potential effects on aquatic systems. This is especially true in the Western Cascades where algal growth in streams draining forested areas is often limited by the supply of nitrogen (Triska and others, 1983; Borchardt, 1996), and in the Little River and North Umpqua River basins where recent data indicate that ambient nitrogen concentrations are relatively low (Anderson and Carpenter, 1998; U. S. Geological Survey, unpublished data, 1998, 1999). If changes in nutrient inputs to streams resulting from fertilization cause changes in algal growth that themselves affect invertebrate grazer abundances, there could be additional effects on secondary consumers such as fish or amphibians.

From a scientific standpoint, this study offers opportunities to examine aspects of fertilization that have not been well documented. Forest fertilization has been studied numerous times for its effects on water quality (table 2*<<should I use the whole table or is it too much?>>)*, especially with respect to maintenance of water quality criteria. In almost all cases investigators have reported immediate but short duration pulses of urea or ammonium, resulting from direct application to streams or from runoff during rainy conditions, at relatively high concentrations; urea-N or total Kjeldahl nitrogen peaks (TKN) are often as high as 10-45 milligrams per liter (mg/L) and ammonium-N peaks are commonly between 0.5 and 1.5 mg/L (table 2, and see NCASI, 1999). Ammonium concentrations, however, have rarely exceed ammonia toxicity standards, largely because temperatures are usually cold when urea-N is applied. After application, urea rapidly hydrolyzes to form ammonium in forest soils or in streams; a portion of the resulting ammonium is later oxidized to nitrate through the process of nitrification (Ochtere-Boateng, 1979; Nason and Myrold, 1992). Ammonium is retained relatively well in soils and plants through cation exchange processes and plant uptake, however nitrate is more easily leached from the soils (Ochtere-Boateng, 1979). Accordingly, increases in stream water nitrate-N concentrations typically appear following those from urea-N and ammonium-N, and are usually lower in magnitude, though often lasting for months, approaching background concentrations during late spring and summer. Nitrate-N usually reaches a secondary peak during rains in the following autumns. Despite these increases, nitrate-N concentrations exceeded the drinking water criterion concentration of 10 mg/L only in one reported study (Edwards and others, 1991) at Fernow Experimental Forest, Virginia, where N-deposition is known to be among the highest in the nation and the soils are considered N-saturated (Fenn and others, 1998). Meanwhile, effects of fertilization on stream biota have only been evaluated, at relatively cursory levels, in two cases (Meehan and others, 1975; Stay and others, 1978, 1979)

Clearly, exceedances of ammonia toxicity and nitrate drinking water criteria are important to monitor during a forest fertilization, given the potential for excess concentrations depending on conditions of hydrology, soil chemistry, and prior disturbance in a watershed. But it is now apparent from the many previous studies that these criteria are rarely exceeded (Bisson and others, 1992; Binkley and Brown, 1993; NCASI, 1999). Rather, it is reasonable to ask at this point whether these are appropriate benchmarks for making decisions about fertilization, or other effects of forest management, in an era of endangered species and apparently disrupted ecosystems. Particularly in nitrogen limited systems such as streams of the western Cascades, where secondary effects of cumulative, increased nutrient loading to streams may include changes in algal growth patterns and their potential collateral effects on pH, DO, and food webs, the relevant benchmarks may instead be various indicators of ecological change.

Therefore, scientific benefits of this fertilization study will include advances in our understanding of biological- and ecosystem-level impacts of forest fertilization, as well as an evolution of the approaches used for evaluating other forestry practices. The intent is to link management actions in the upland areas (fertilization) with inputs of nutrients to streams and further to changes in algal growth, production, and(or) community composition. Effects of fertilization on amphibians, possibly the top level predators in some stream reaches, will be studied concurrently by scientists from the Biological Resources Division BRD) and from Oregon State University (OSU), providing a rare opportunity to document an entire stream ecosystem response by linking bottom-up effects on algal growth with top-down effects from amphibians. There is also a possibility of incorporating work on hyporheic processes to document subsurface effects at stream margins from inputs of nutrients through mechanisms previously unexamined in fertilization studies. This aspect would provide an important link between the application of fertilizer and nutrient loading to streams. Work in hyporheic zones may be conducted by researchers from the National Research Program (NRP) and(or) from OSU. Funding for hyporheic work will likely be pursued independently but it’s procurement would be augmented by a well established and funded base-level program.

The above illustrates the third major benefit of this study. By facilitating and coordinating research at different scales by scientists from WRD, BRD, NRP, and

OSU, with oversight and direction from the Bureau of Land Management, the Oregon District would be able to help establish vital and important relationships within the USGS, between the USGS and the BLM, and between USGS and OSU.

5.0 Approach

Proposed work elements for this study are given in table 3. As can be seen from the table and the previous discussion, this project is both ambitious and complex. The anticipated length of the study extends into FY02, and beyond for some work elements such as report writing. Successfully meeting the stated objectives will depend on careful selection of stream reaches and locations, obtaining complete data on upstream physical attributes and land use histories, appropriate consideration of scale (both spatial and temporal) in examining different questions, understanding of previous scientific research and methods for evaluating the key processes, careful planning, and adequate funding. The Oregon District of WRD will act in both scientific and coordinating roles in this study, addressing the basic endpoints of the stated objectives (measuring changes in algal communities and biomass, documenting changes in water quality including nutrient inputs and status of pH and DO, and examining to the extent possible the cumulative downstream impacts of fertilization on the Little River), while participating with other researchers to examine the more fine-scale, process-oriented questions.

Many of the items in table 3 and their projected completion dates will be dependent on previous results, particularly in FY02 and FY03. Most previous studies have detected increased nitrate concentrations from fertilization during the fall of the year following fertilization, but few have extended beyond one year after fertilization. Decisions about extending this study to include data collection beyond the fall of the year following fertilization (that is, fall FY02) will be made in consultation with the BLM during winter FY02 based on results to date, and again in winter FY03 if necessary. Additional work elements and their timelines, including those for reports, will be finalized in writing at those times.

5.1 Spatial scales

This study is envisioned to be conducted at several different scales so as to assess mechanistic and subtle water quality processes at the tributary or reach scales as well as cumulative impacts at the subbasin and basin scales. BLM's plans for fertilization in the Little River Basin include up to 2,400 acres (971 hectares) of forest land, with proposed fertilization units occurring in smaller parcels scattered around the BLM's 19,802 acres (8,014 hectares) in the basin. Because of this scattering of fertilization units, detecting impacts on water quality at the scale of the Little River resulting from individual fertilizer units may be difficult. However, a relatively large number of proposed fertilization units (1,310 acres, or 530 hectares) are located within the Wolf Creek subbasin (fig 1). Wolf Creek is a third to fourth order stream with a highly incised valley in the lower reaches and near it's mouth and broad, plateau-like uplands. An extensive network of logging roads within the subbasin make many of Wolf Creek's tributary streams accessible at different elevations and at both upstream and downstream ends of the stands proposed for fertilization. Controls for comparison with treated streams will include upstream ends of streams in treated stands, control-treatment watershed pairs, and one or two reference locations within the AMA. BLM has indicated a willingness to withold select fertilization units from fertilization in order to create control watersheds for treated stands.

Therefore the study will focus primarily on fertilizer impacts within the Wolf Creek Basin and immediately below Wolf Creek in the Little River, while continuing to monitor in Little River at selected sites. However, work will also be done in the smaller first order tributaries to Wolf Creek to try to describe fertilizer inputs and any impacts from a more process-oriented standpoint. Specifically, the study will be carried out simultaneously at 3 spatial scales, with a variety of data types being collected at each scale:

- Large scale - Cumulative effects, looking for impacts on fish bearing streams. Includes a few sites in Little River. Analyses: stream chemistry, algal biomass and species, diel DO / pH.
- Medium scale - Cumulative effects in Wolf Creek, including some lands that

may be affected by private timberland fertilization. Analyses: synoptic studies of stream chemistry, algal biomass and species; Water quality monitor for DO, pH, temperature, specific conductance; stable isotopes as tracers. Coordinate with BRD.

- Subbasin scale - Control/treatment pairs for detailed characterization of stream morphology and habitat, algal species and food-web analysis, comparison on effects between pair members. University and/or NRP researchers also conduct experiments to measure primary production, hyporheic zone processes, stable isotopes or tracer experiments, effects of riparian buffers, and others. Coordinate with BRD.

5.2 Temporal scales

Natural variability will be evident in temporal patterns of DO and pH, stream nutrient concentrations, and biological communities regardless of fertilization inputs. Therefore, several methods will be used to measure temporal variability in order to distinguish impacts from fertilization from natural variations in environmental processes.These will include sampling for at least one year prior to and after fertilization, use of recording streamgages and water quality monitors, sampling for water quality monthly at select locations and during stormflows, and intensive sampling during fertilization to capture peak concentrations that may occur from accidental direct applications and from nitrification of applied urea-N.

5.3 Non-standard techniques are necessary

Many of the processes that could contribute materially to stream changes resulting from fertilization are subtle and their documentation may require different approaches than have been used in past fertilization studies. For instance, changes in benthic algal growth resulting from changes in nutrient regimes may be manifested either in increased biomass and/or chlorophyll a (Grimm and Fisher, 1986; Bothwell, 1992; Tanner and Anderson, 1996; Borchardt, 1996; Harvey and others, 1998), or alternatively as a change in algal speciation or production rate that is offset by increased consumption by macroinvertebrate grazers (Biggs and others, 1998), as seen by Lundberg (1996) in the nearby H. J. Andrews Experimental Forest. Similarly, nutrient inputs from fertilization may follow patterns observed in many fertilizer studies (table 2; Bisson, 1992; NCASI, 1999) where increased ambient streamwater concentrations are evident during rainy periods in fall, winter, and spring, but may appear to be at background levels during summer. Yet algal uptake and recycling (Mullholland, 1992; Paul and others, 1991) can be so efficient, especially in a nitrogen-limited stream during summer, that inputs of nitrogen in hyporheic flow (groundwater) might be immediately consumed and retained in biomass (Kim and others, 1992; Boulton and others, 1998; Dahm and others, 1998). Thus routine water-column sampling might miss these inputs without also measuring nutrients stored in benthic algal biomass and(or) transported in particulate, sloughing algae. Finally, many of the streams within the fertilization units are small (summer discharges <<1 cfs) and algal growth is most likely limited by light rather than nutrients. In these streams nutrient transport may be enhanced without much effect on benthic communities; whereas, in downstream reaches that are larger and with more open canopies, the cumulative effect of upstream nutrient transport may enhance benthic utilization of nutrients. This study will incorporate considerations of these and other effects in attempting to detect and evaluate the impacts of environmental change from forest fertilization. Information on specific work categories and selected tasks is given in section 9.0.

6.0 Reports

This study has the potential to provide a wide array of information that indicate new scientific findings in several topical areas, including ecological impacts of forest fertilization, forest management impacts on water quality, food web relationships in streams, and linkages between upland, hyporheic, and instream processes. Therefore a series of journal publications on independent, single-topic reports are indicated in table 3. Journal articles are desired for several reasons: (1) the study is potentially complex enough that smaller, limited-issue reports will be the best way to portray the information for a given topic; (2) the exposure of journal articles is wider than for most USGS report outlets, meaning any unique findings on the widespread practice of forest fertilization will get the largest distribution; and (3) to help encourage participation by researchers from NRP and OSU, for whom journal articles are the preferred publication outlet. A data report will be considered, in consultation with the Bureau of Land

Management, with the publication to be a USGS Open-file report and (or) electronic database, as will publication of a short fact sheet to synthesize the results of all reports from the project and to inform the public and land managers about them. The BLM and Forest Service already operate a web page (http://www.teleport.com/~lrama/index.html) for the LRAMA on which information on relevant studies (including this one) are posted.

Draft timelines for most of the reports (table 3) are staggered so as to allow initial data and analysis to be completed for reports that build on previous analyses. For that reason some reports are anticipated to be completed in FY03. Timelines for all reports will be confirmed with BLM in early FY02 once fall sampling in FY02 is completed and the data analyzed. If BLM and USGS both feel that additional data collection is warranted then some reports may be postponed until after data collection is complete. In any case, deadlines for reports on food webs, cumulative impacts of fertilization, linkages between uplands and streamwater, and a synthesis report/fact sheet are likely to extend beyond FY02 to allow data analysis and writing to be completed for the other study products.

7.0 Budget

8.0 Personnel

9.0 Workplan

<<are these explanations necessary or too much detail?>>

Information infrastructure— Several types of continuous data will be needed in order to (1) understand changes in the Little River and in Wolf Creek in the context of natural variability, (2) extrapolate results from the subbasin to the basin scale, and (3) to help make decisions about sampling during winter storm events and summer low flow periods. These include streamgages, weather stations, and water quality monitors. Consultations for semipermanent installations of any equipment will be made with BLM and other appropriate agencies to conform to requirements for fish passage and land disturbance in forested areas.

Continuous streamflow data will be necessary to estimate constituent loads and to understand hydrologic conditions during the project. There is only one active streamgage in the Little River Basin, a site reestablished in conjunction with the BLM and Forest Service in 1999 at the historical Peel gage (fig.1). Additional short-term sites will be evaluated at the mouth of Wolf Creek and in selected tributaries to Wolf Creek.

The BLM and the Forest Service currently operate four-parameter water-quality monitors, in Cavitt Creek near the mouth and in the Little River upstream of Cavitt Creek, during low flow periods in August and September (Debra Gray and Mikeal Jones, USDA Forest Service, written commun. 1999). These data are valuable for providing data on diel variations and summer patterns in parameters such as pH, DO, and temperature. Additional monitors located in Wolf Creek near the mouth or in selected tributaries will help provide information more specific to the fertilization and its effects on Wolf Creek.

Stream Sampling— Monthly sampling is planned for the duration of the project to help understand variability in nutrient concentrations and loads before and after fertilization. Sampling during and immediately after fertilization will be intensive in order to detect high concentration peaks of urea and ammonium and to determine when nitrate concentrations begin to increase. Nitrate concentrations typically increase in response to rainfall runoff in fall and spring, so the initial storms will be sampled during fall as well as at least 3 storms each winter and spring, to characterize peak runoff of nutrients before and after fertilization. Changes in benthic primary production may be one important response to increased fertilizer-nutrient inputs, so measurement of primary production will be carried out in selected streams before and after fertilization. This will be done by whole stream metabolism techniques using stream tracers (Marzolf and others, 1994, 1998; Mullholland and others, 1997, 1999) or by benthic chambers (Gregory, 1993; Bott and others, 1997), with decisions to be based on conversations with other researchers during winter 2000. Prior channel characterizations will help select locations for making primary production measurements. Synoptic samplings will occur once each spring and at least twice during each summer of data collection. Samples will be collected for water quality analyses, algae, and possibly invertebrates or, in conjunction with researchers from BRD, amphibian abundance.

Refine and test field methods for fertilization– An opportunity to test methods and conceptual models for sampling during the actual fertilization period will be presented in fall 1999. Forest fertilizations are planned for other locations in the Umpqua Basin (C. Kintop, Bureau of Land Management, oral commun., 1999) during fall 1999. Changes in specific conductance attributed to fertilization with urea (and resulting cation exchange) were reported by Edwards and others (1991), so deployment of a continuous monitor to measure for specific conductance may prove fruitful in looking for a signature of the applied fertilizer. Also, because concentrations of ammonium immediately after application are sometimes in the milligram per liter range, use of an ion-selective electrode for ammonium on a deployed monitor could help catch temporary and fleeting peaks in N concentrations. Both of these types of data would help screen for suitable samples to submit for laboratory analysis, helping to be more selective in sample collection. Automatic samplers that effectively sample in proportion to flow and that are able to capture samples cleanly could be tested for their effectiveness in sampling transient, storm-flow driven peaks in applied urea-N. Also, the possibility that applied urea-N develops a unique isotopic ^{15}N signature relative to background conditions (see below) could be investigated. Finally, it will be necessary to measure the actual application rate on the ground, a process for which several different collectors have been proposed. These methods will be tested and if any of them prove successful then they would be utilized during fertilization in the Little River Basin to help quanitify the effective fertilization rate there.

Isotopic Tracer (^{15}N)— Use of stable isotopes of nitrogen might prove to be one of the most effective and definitive methods for tracing the movement of applied urea-N into the stream ecosystems. This is especially true for N in water and biota during summer months, when changes in N speciation and biological uptake will mask inputs from previous months or from groundwater and hyporheic zones. The isotopic signature of urea is expected to be near background (that is, $\delta^{15}N \cong 0$‰); however, volatilization (Ochtere-Boateng, 1979; Nason and others, 1988; Nason and Myrold, 1992) and fractionation during uptake (Jordan and others, 1997; <*Udy and Dension, 1997*>) may alter the isotopic signature of N that leaches from the soil to the streams. If this is the case, and isotopically enriched N is taken up by stream biota, then the movement of urea-N to the stream could be readily traced. To this end several samples of mosses and periphytic algae were submitted in August 1999 for analysis to help determine background ^{15}N levels and to see if volatilization from urea-N applied to private timber lands in the fall produced such a signature. If this method proves unsuccessful, then urea that is artificially enriched with ^{15}N will be applied to one or more fertilization units in which streams draining them are unaffected by previous fertilizations on private lands. Verbal agreement that this technique would be allowed has already been given by the BLM.

One major issue with use of ^{15}N-labelled urea will be cost. In an ongoing, watershed-scale nitrogen-enrichment experiment at Bear Brook Forest in Maine to simulate N-deposition and forest N-saturation, Fry and others (1995) have added ^{15}N-labelled ammonium sulfate at a rate of 150 kilograms (kg) per hectare (ha) annually to a 10 hectare site for an annual cost of $10,000. Scaling this cost directly to an example 0.2 square mile (52 ha) fertilization unit in the Little River Basin (that has perennial streamflow), with an application rate of 224 kg/ha, yields a resulting cost is of $74,600. Even if ^{15}N labelled urea proves to be slightly cheaper than ^{15}N-labelled ammonium sulfate (all forms of ^{15}N are apparently made from urea), the potential costs are clearly high to use ^{15}N-enriched fertilizer at a subbasin scale. The use of these techniques, however, would greatly enhance the likelihood of successfully tracing applied nitrogen into stream biota.

GIS Support— The complexity of land-use and land-ownership patterns in the Little River Basin will make good GIS support an important component of this study. GIS products will be used to understand upstream land uses and help make decisions on sampling locations, to quantify subbasin areas, and to portray information for reports or presentations. Coverages for BLM lands in the basin, including location of proposed fertilization units, land ownership, tree-stand age, geology, roads, and more have already been obtained, however land use history for National Forest and private timber lands in the basin have not been. National Forest land coverages will be readily available; however, care and patience will be needed to obtain information from private timber companies. These data will be critical because of the patchwork pattern of land ownership in the basin, which renders almost all perennially flowing streams subject to upstream influences from multiple landowners.

Administrative— One administrative task in table 3 that bears explanation is the certification and contracting of a laboratory for doing water quality analysis. Experience by the USGS in Cascade streams indicate that a laboratory other than the National Water Quality Laboratory (NWQL) may be needed for nutrient analyses for this project. The NWQL provides high-quality data for most nutrients at moderate- to high levels; however, data on organic nitrogen from the NWQL are highly variable at concentrations near or below the 100 microgram per liter (ug/L) minimum reporting limit (MRL), and data for other nutrients can vary considerably at low levels as well. Data from the North Umpqua River (Anderson and Carpenter, 1998), Clackamas River (K. Carpenter, U.S. Geological Survey, Unpublished Data, 1998), and reconnaissance data from the Little River Basin collected during 1998 and 1999 indicate that organic-N concentrations near or below 100 ug/L are common in these streams. Yet algal species data suggest that organic-N is one of the key forms of nitrogen fueling algal growth in many of these same streams (Anderson and Carpenter, 1998); furthermore, several different studies of have identified organic-N as the largest component of stream nitrogen budgets in Cascade streams (Sollins and others, 1980; Triska and others, 1984; Martin and Harr, 1988). Thus one of the potentially most important constituents for this study is likely to be the one with the poorest quality data if samples are analyzed at the NWQL. Although Methods and Development personnel at the NWQL intend to test a new method for organic-N analysis that would provide lower MRLs, testing has been delayed for several years and is not yet scheduled, much less approved for submission of district samples (C. J. Patton, U.S. Geological Survey, written commun., July 1999)

For this reason, an effort is already underway to certify (according to WRD memo QW98.03) and use the Central Chemical Analytical Laboratory (CCAL) at Oregon State University. CCAL has a history of analyzing low-level nitrogen, including organic nitrogen, in waters from Cascade streams. CCAL's reporting limit for both filtered and unfiltered Kjeldahl-nitrogen analyses is 10 ug/L. Preliminary standard reference quality-assurance samples for oganic-N submitted to CCAL in 1999 indicated a very good ability to meet an expected value that was less than half of the NWQLs MRL. Data from the NWQL for analysis of the same samples have not yet been received. Another reason for using CCAL for nutrient analyses in this project is that researchers from OSU are likely to use the same laboratory if they become involved in the project. This will therefore help make data more transferable between different aspects of the study. Finally, analytical costs at CCAL are currently about 33% less than the NWQLs costs for nutrient analysis, so money would be saved over the long run analytical costs.

REFERENCES

Adams, P.W. and Stack, W.R., 1989, Streamwater quality after logging in southwest Oregon: Portland, Oregon, Project completion report supplement number PNW 87-400, USDA Forest Service, Pacific Northwest Research Station, 19 p.

Anderson, C. W., and Carpenter, K. D., 1998, Water quality and algal conditions in the North Umpqua River Basin, Oregon, 1992— 95, and implications for resource management: U.S. Geological Survey Water-Resources Investigations Report 98–4125, 78 p + 1 plate.

Biggs, B.J.F., Stevenson, R.J., and Lowe, R.L., 1998, A habitat matrix conceptual model for stream periphyton: Archiv fur Hydrobiologie, v. 143, no. 1, p. 21-56.

Binkley, D., 1986, Forest nutrition management: New York, Wiley Interscience, p. 108-133

Binkley, D., Allan, H.L., and Burnham, H., 1999, Water quality effects of forest fertilization: National Council for air and stream improvement 782.

Binkley, D., and Brown, T.C., 1993, Forest practices as nonpoint sources of pollution in North America: Water Resources Bulletin, v. 29, p. 729-740.

Bisson, P.A., 1982, Annual fertilization and water quality - final report: Weyerhauser Company Technical Report 050-5411-02, Centralia, WA

Bisson, P.A., 1988, 1988 Weyerhauser forest fertilization / water quality monitoring studies-Forks Creek, Ryderwood, Silver Lake: Weyerhauser Company Technology Center, Tacoma, WA

Bisson, P.A., Ice, G. C., Perrin, C., Bilby, R., 1992, Effects of forest fertilization on water quality and aquatic resources in the Douglas-fir region, *in* Chappell, H.N., Weetman, G.F., and Miller, R.E., eds., Forest Fertilization: sustaining and improving growth of western forests: Seattle, WA, University of Washington, Institute of Forest Resources, Contribution 72, p. 179-193

Borchardt, M.A., 1996, Nutrients, *in* Stevenson, J.R., Bothwell, M.L., and Lowe, R.L., eds., Algal ecology—Freshwater benthic ecosystems: San Diego, California, Academic Press, Inc., p. 183–227.

Bothwell, M.L., 1992, Eutrophication of rivers by nutrients in treated kraft pulp mill effluent: Water Pollution Research Journal of Canada, v. 27, no. 3, p. 447-472.

Bott, T.L., Brock, J.T., Baattrup-Pedersen, A., Chambers, P.A., Dodds, W.K., Himbeault, K.T., Lawrence, J.R., Planas, D., Snyder, E., and Wolfaardt, G.M., 1997, An evaluation of techniques for measuring periphyton metabolism in chambers: Canadian Journal of Fisheries and Aquatic Sciences, v. 54, p. 715-725.

Boulton, A.J., Findlay, S., Marmonier, P., Stanley, E.H., and Valett, H.M., 1998, The functional significance of the hyporheic zone in streams and rivers: Annual Reviews of Ecology and Systematics, v. 29, p. 59-81.

Cline, C., 1973, The effects of forest fertilization on the Tahuya River, Kitsap Peninsula, Washington: State of Washington, Department of Ecology 74-2.

Cole, D.W., and Gessel, S. P., 1965, Movement of elements through a forest soil as influenced by tree removal and fertilizer additions, *in* Yougberg, C.T., *ed*., Forest-soil relationships in North America: Corvallis, Oregon, Oregon State University Press, p. 95-104

Dahm, C.N., Grimm, N.B., Marmonier, P., Valett, H.M., and Vervier, P., 1998, Nutrient dynamics at the interface between surface waters and groundwaters: Freshwater Biology, v. 40, p. 427-451.

Edwards, P.J., Kochenderfer, J.N., and Seegrist, D.W., 1991, Effects of forest fertilization on stream water chemistry in the Appalachians, Water Resources Bulletin, v. 27, n. 2, pp 265-274

Fenn, M.E., Poth M.A., Abe J.D., Barron J.S., Bormann B.T., Johnson D.W., Lemly A.D., McNulty S.G., Ryan D.F., and Stottlemeyer R., 1998, Nitrogen excess in North American ecosystems: predisposing factors, ecosystem responses, and management strategies: Ecological Applications, v. 8, n. 3, p. 706-733.

Frederiksen, R.L., Moore, D.G., and Norris, L.A., 1975, The impact of timber harvest, fertilization, and herbicide treatment on streamwater quality in western Oregon and Washington, pp 283-313, *in* Bernier, B., and Winget, C., *eds*., Forest Soils and Forest Land Management– Proceedings of the Fourth North American Forest Soils Conference, Laval University Press, Quebec, Canada

Fry, B., Jones, D.E., Kling, G.W., McKane, R.B., Nadelhoffer, K.J., and Peterson, B.J., 1995, Adding ^{15}N tracers to Ecosystem Experiments, *in* Wada, E., ed., Stable isotopes in the biosphere: Kyoto, Kyoto University Press, p. 171-191.

Gregory, S.V., 1993, Willamette River Basin - Periphyton algal dynamics [Final report to the Oregon Department of Environmental Quality]: University of Oregon.

Grimm, N.B., and Fisher, S.G., 1986, Nitrogen limitation in a Sonoran Desert Stream: Journal of the North American Benthological Society, v. 5, p. 2-15.

Harvey, C. J., Peterson, B. J., Bowden, W. B., Hershey, A. E., Miller, M. C., Deegan, L. A., and Finlay, J. C., 1998, Biological responses to fertilization of Oksrukuyik Creek, a tundra stream: J. N. Am. Benthol. Soc., v. 17, n. 2, p. 190-209.

Helvey, J.D., Kochenderfer, J.N., and Edwards, P.J., 1989, Effects of forest fertilization on selected ion concentrations in central Appalachian streams, *in* Proceedings of the seventh central hardwood conference: St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Carolina Forest Experiment Station, Gen. Tech. Rep. NC-132, pp 278-282

Hetherington, E.D., 1985, Streamflow nitrogen loss following forest fertilization in a southern Vancouver Island watershed: Canadian Journal of Forest Research, v. 15, p 34–41

Jordan, M.J., Nadelhoffer, K.J., and Fry, B., 1997, Nitrogen cycling in forest and grass ecosystems irrigated with 15N-enriched wastewater: Ecological Applications, v. 7, no. 3, p. 864-881.

Kim, B.A., Jackman, A.P., and Triska, F.J., 1992, Modeling biotic uptake by periphyton and transient hyporheic storage of nitrate in a natural stream: Water Resources Research, v. 28, no. 10, p. 2743-2752.

Lundberg, C.H., 1996, The effects of grazing and nitrogen enrichment on the taxonomic structure of periphyton assemblages in lotic ecosystems: Corvallis, Oregon, Oregon State University, Masters, 120 p.

Malueg, K.W., Powers, C.F., and Krawczyk, D.F., 1972, Effects of aerial forest fertilization with urea pellets on nitrogen levels in a mountain stream: Northwest Science v. 46, n. 1, pp 52–58

Martin, C.W., and Harr, R.D., 1988, Precipitation and streamwater chemistry from undisturbed watersheds in the Cascade Mountains of Oregon: Water, Air, and Soil Pollution, v. 42, no. 1, p. 203-219.

Marzolf, E.R., Mulholland, P.J., and Steinman, A.D., 1994, Improvements to the diurnal upstream-downstream dissolved oxygen change technique for determining whole-stream metabolism in small streams: Canadian Journal of Fisheries and Aquatic Sciences, v. 51, no. 1591-1599.

Marzolf, E.R., Mulholland, P.J., and Steinman, A.D., 1998, Reply: Improvements to the diurnal upstream-downstream dissolved oxygen change technique for determining whole-stream metabolism in small streams: Canadian Journal of Fisheries and Aquatic Sciences, v. 55, p. 1786-1787.

Meehan, W.R., Lotspeich, F.B., Mueller, E.W., 1975, Effects of forest fertilization on two southeast Alaska streams: J. Environmental Quality, v. 4, p. 50-55.

Moore, D.G., 1971, Fertilization and water quality, *in* Western Reforestation — Proceedings of the Annual Meeting of the Western Reforestation Coordinating Committee: Western Forest Conservation Association, p. 28-31

Moore, D.G., 1975, Impact of forest fertilization on water quality in the Douglas-fir region -- A summary of monitoring studies: New York, Proceedings of the 1974 National Convention, Society of American Foresters, p 209–219

Mulholland, P.J., 1996, Role in nutrient cycling in streams, *in* Stevenson, J.R., Bothwell, M.L., and Lowe, R.L., eds., Algal ecology-Freshwater benthic ecosystems: San Diego, California, Academic Press, Inc., p. 609-639.

Mulholland, P.J., Marzolf, E.R., Webster, J.R., Hart, D.R., and Hendricks, S.P., 1997, Evidence that hyporheic zones increase heterotrophic metabolism and phosphorus uptake in forest streams: Limnology and Oceanography, v. 42, no. 3, p. 443-451.

Nason, G. E., and Myrold, D. D., 1992, Nitrogen fertilizers: Fates and environmental effects in forests, *in* Chappell, H. N., Weetman, G. F., and Miller, R. E., *eds*., Forest Fertilization: Sustaining and improving nutrition and growth of western forests: Seattle, University of Washington, Institute of Forest Resources, Contribution No. 73, pp. 67–81

Nason, G.E., Pluth, D.J., and McGill, W.B., 1988, Volatilization and foliar recapture of ammonia following spring and fall application of nitrogen-15 urea to a Douglas-fir ecosystem: Soil Science Society of America Journal, v. 52, p. 821-828.

NCASI (National Council of the Paper Industry for Air and Stream Improvement), 1999, Water quality effects of forest fertilization: Research Triangle Park, N.C., Technical Bulletin No. 782, 53 p.

Norris, L.A., Lorz, H.W., and Gregory, S.V., 1991, Forest chemicals, *in* W.R. Meehan, ed., Influences of forest and rangeland management on salmonid fishes and their habitats: Bethesda, Maryland, American Fisheries Society, Special Publication 19, p. 207–296.

Ochtere-Boateng, J., 1979, Reaction of nitrogen fertilizers in soils, *in* Gessel, S. P., Kenady, R. M., and Atkinson, W. A., eds., Proceedings of the Forest Fertilization Conference: Union, Washington, University of Washington, College of Forest Resources, Institute of Forest Resources Contributin No. 40, p. 37-47

Oregon Department of Environmental Quality, 1999, Final 1998 303(d) Database: URL < http://waterquality.deq.state.or.us/WQLData/SubBasinList98.asp>, Accessed August 26, 1999.

Paul, B.J., Duthie, H.C., and Taylor, W.D., v. 10, no. 1, p. 31-41., 1991, Nutrient cycling by biofilms in running waters of different nutrient status: Journal of the North American Benthological Society, v. 10, no. 1, p. 31-41.

Perrin, C.J., Shortreed, K.S., and Stockner, J.G., 1984, An integration of forest and lake fertilization: transport and transformations of fertilizer elements: Canadian Journal of Fisheries and Aquatic Sciences, v. 41, p. 253-262.

Powell, M.A., 1995, Report on pH in the Jackson Creek and Little River drainage basins of the Umpqua National Forest: Roseburg, Oregon, U.S. Department of Agriculture, Forest Service, Umpqua National Forest, Draft report to the U.S. Forest Service, [variously paged].

———, 1997, Water quality concerns in restoration of stream habitat in the Umpqua Basin, in Hall, J.D., Bisson, P.A., and Gresswell, eds., Searun cutthroat trout—Biology, management, and future conservation: Corvallis, Oregon Chapter, American Fisheries Society, p. 129–130.

———, 1998, Umpqua National Forest Water Quality Study, 1998: Roseburg, Oregon, USDA Forest Service, 13 p plus mabs, tables, and figures.

Sollins, P., Grier, C.C., McCorison, F.M., Cromack, K., and Fogel, R., 1980, The internal element cycles of an old-growth Douglas-fir ecosystem in western Oregon: Ecological Monographs, v. 50, no. 3, p. 261-285.

Sollins, P., and McCorison, F.M., 1981, Nitrogen and carbon solution chemistry of an old growth coniferous forest watershed before and after cutting: Water Resources Research, v. 17, n. 5, p 1409–1418

Stay, F.S, Malueg, K.W., Austin, R.E., Crouse, M.R., Katko, A., and Dominguez, S.E., 1978, Ecological effects of forest fertilization with urea on small Western Cascade streams of Oregon, U.S.A.: Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie, v. 20, p. 1347-1358

Stay, F.S, Katko, A., Malueg, K.W., Crouse, M.R., Dominguez, S.E.,and Austin, R.E., 1979, Ecological effects of forest fertilization major biological components of small Cascade streams, Oregon: Corvallis, Environmental Protection Agency Report EPA-600/3-79-099, 18 p

Tamm, C. O., Holmen, H., Popovic, B., and Wiklander, G., 1974, Leaching of plant nutrients from soils as a consequence of forestry operations: Ambio, v. 3, n.6., p. 211–221

Tanner, D.Q., and Anderson, C.W., 1996, Assessment of water quality, nutrients, algal productivity, and management alternatives for low-flow conditions, South Umpqua River Basin, Oregon, 1990–92: U.S. Geological Survey Water-Resources Investigations Report 96–4082, 71 p.

Tiedemann, A.R., Helvey, J.D., and Anderson, T.D., 1978, Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington: Journal of Environmental Quality, v. 7, no. 4, p. 580-588.

Tiedeman, A.R., Quigley, and T. M., Anderson, T.D., 1988, Effects of timber harvests on stream chemistry and dissolved nutrient losses in northeast Oregon: Forest Science, v. 34, n. 2, p. 344-458

Triska, F.J., Kennedy, V.A., Avanzino, R.J., and Reilly, N.B., 1983, Effect of simulated canopy cover on regulation of nitrate uptake and primary production by natural periphyton communities, *in* Fontain, T.D., and Bartell, S.M., eds., Dynamics of lotic ecosystems: Ann Arbor, Michigan, Ann Arbor Science Publishers., p. 129–159.

Triska, F.J., Sedell, J.R., Cromack, K.J., Gregory, S.V., and McCorison, F.M., 1984, Nitrogen budget for a small coniferous forest stream: Ecological Monographs, v. 54, no. 1, p. 119-140.

Udy, J.W., and Denison, W.C., 1997, <<Still need to get this title>>: Journal of Experimental Marine Biology and Ecology, v. 217, p. 253-277.

U.S.D.A. Forest Service and Bureau of Land Management, 1994, Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the ranges of the Northern Spotted Owl: U.S. Forest Service and Bureau of Land Management, April 1994, 74 p.

——— 1995, Little River watershed analysis, version 1.1: Roseburg, Oregon, U.S.D.A. Forest Service, North Umpqua Ranger District, [variously paged].

U. S. Geological Survey, 1999, Strategic Management Plan, url <<http://www.usgs.gov:8888/strat_plan/ppc_message.html>>, accessed August 25, 1999

Table 2. Summary of studies of forest fertilization effects on stream-water quality.
[Conversions: 1 kg/ha = .89 lb/ac; 1kg Urea = .46 kg N; NR, not reported;

Geographical area and streams studied	Baseline N. Conc. (ug/L)	Maximum Post-treatment Conc. (ug-N/L)	Estimated period and avg. magnitude of elevated concentration[a], vs control or baseline	% loss to streams	Biological Components studied and results	Sampling Design / Remarks
Location: Santiam Basin, Oregon; Application rate: 224 kg N/ha urea; Date: May 1969; Objectives: Effects of fertilization on water quality; Reference: Malueg and others, 1972.						
Crabtree Creek (Control is upstream)	NH3 <10 NO3 <10 TKN 400	NH3 80 NO3 250 TKN 24,000	NH3 >100d, ~3x NO3 >7mo, 1.5- 2x TKN 2d, ~75x	NR	NR	Also performed assays on urea pellets (NH_3-N, 140 mg/kg; NO_2-N, 0.53 mg/kg; NO_3-N, 19.33 mg/kg; TKN, 440,000 mg/kg). Nitrate returned to baseline during summer but peaked again in fall with precipitation
Location:Tahuya River, Kitsap Pennisula, WA.; Application rate: 227 kg N/ha; Date: October 1972; Objectives: Effects of fertilization on water quality; Reference: Cline, 1973						
Site 1 (Upstream Control)	NH3 10-80 NO3 0-200 Urea 0-10	NH3 <10 NO3 470 Urea 50	NA	NA	NR	Water quality data collected at all sites for 1 yr at all sites prior to fertilization. In general NO3 responded to flow. Conditions were dry for ~31 days after fertilization.
Site 2 (no buffer strip)	NH3 10-80 NO3 40-210 Urea 10-20	NH3 1,400 NO3 1,830 Urea 27,000	NH3 25d, ~30-60x NO3 ~7.5 mo, ~8x Urea 6d, ~40x	NR	NR	Lack of buffers contributed to increased nutrient concentrations compared to site 3. NH3 peaks were also more immediate than at site 3 due to direct application.
Site 3 (buffer strip)	NH3 0-60 NO3 0-260 Urea 10-20	NH3 160 NO3 680 Urea 4,300	NH3 2d, 10-40x NO3 ~7.5mo, ~3x Urea 6d, ~40x	NR	NR	NH3 peaks were delayed by more than a month and lowered due to dry weather in fall.
Sites 4 & 5 (downstream sites)	NH3 0-80 NO3 0-350 Urea 0-30	NH3 60 NO3 470 Urea 40	NH3 ~31d, ~3-5x NO3 ~31d, ~4x Urea ~3d, ~2x	.45%	NR	NH3 peaks were delayed by more than a month and lowered due to dry weather in fall. Loss of nitrogen reported is for the entire study area (sites 2,3,4, & 5) upstream compared to control.
Location: SE Alaska; Application rate: 210 kg urea-N/h; Date: May 1970; Objectives: MCL, NH3 toxicty exceedances; Reference: Meehan and others, 1975						
Falls Creek, Control	NH3 ~20 NO3 ~10	NH3 ~100 NO3 ~200	NA	NR	Benthic inverts, algal biomass on plexiglass slides. No significant differences found between treatment and control. High variability. No species data taken	Application was to recently logged watersheds. Water sampled daily for first month after application, weekly for 2nd month, and monthly for 1.5 yrs. Very low stream temperatures, average pH 6.5-7.2. Three Lakes unit dried up during summer. Phosphorus did not respond to fertilization.
Falls Creek, Treatment	NH3 ~20 NO3 ~20	NH3 1,280 NO3 ~1,600	NH3 ~ 1.5 mo, 10-20x NO3 ~ 14 mo, 5-10x	NR		
Three Lakes Creek, Control	NH3 ~20 NO3 ~20	NH3 ~100 NO3 ~300	NA	NR		
Three Lakes Creek, Treatment	NH3 ~50 NO3 ~10	NH3 ~100 NO3 2,360	NH3 ~5 d, ~3x NO3 ~1.5 mo, >5x	NR		

Table 2. Summary of studies of forest fertilization effects on stream-water quality.
[Conversions: 1 kg/ha = .89 lb/ac; 1kg Urea = .46 kg N; NR, not reported;

Geographical area and streams studied	Baseline N. Conc. (ug/L)	Maximum Post-treatment Conc. (ug-N/L)	Estimated period and avg. magnitude of elevated concentration[a], vs control or baseline	% loss to streams	Biological Components studied and results	Sampling Design / Remarks
Location: 6 locations in Pacific Northwest; Application rate: 224 kg urea-N/h; Date: March-April, 1970-72; Objectives: not reported; Reference: Moore, 1991, Fredriksen and others, 1975						
Coyote Creek, S. Umpqua Experimental Forest	NH3 5 NO3 2 Urea 6	NH3 48 NO3 177 Urea 1,390	NH3 ~5 d, ~2x NO3 ~2 mos, ~5-10x Urea ~15 d, ~10x	0.01	NR	After 3-6 wks all loss of N was as NO3. Little or no loss of N during summer months, but NO3 had a second peak during rains next fall(~170 ug/L). 92% of N lossed during 1st year was during storms next fall. 100% of watershed area treated, old growth mixed conifers.
Trapper Creek, Olympic National Forest	NH3 0 NO3 34 Urea 8	NH3 10 NO3 121 Urea 700	NR	NR	NR	<10% of watershed area treated, 40 year old Douglas fir stands
Jimmy-Come-Lately Cr., Olympic National Forest	NH3 0 NO3 5 Urea 2	NH3 40 NO3 42 Urea 708	NH3 - NR NO3 - 9wks Urea - NR	NR	NR	<10% of watershed area treated, 10 year old Douglas fir stands
Neslon Creek, Siuslaw River Basin	NH3 10 NO3 290 Urea <20	NH3 320 NO3 2100 Urea 8,600	NR	NR	NR	100% watershed area treated, young Douglas fir growth
Dollar Creek, McKenzie River Basin	NH3 30 NO3 60 Urea <20	NH3 490 NO3 130 Urea 44,400	NR	NR	NR	100% of watershed area treated, young Douglas fir growth
Pat Creek, Yamhill River Basin	NH3 7 NO3 70 Urea 3	NH3 34 NO3 388 Urea 3,260	NR	NR	NR	63% of watershed area treated, 35 year old Douglas fir growth
Location: 25 Locations on 9 streams in Oakridge Ranger District, Willamette National Forest, Oregon; Application rate: 225 kg N/ha urea; Date: April 1976; Objectives: Determine effects on selected chemical and biological aspects of streams; Reference: Stay and others, 1978., Stay and others, 1979						
Site 25 (Control)	NH3 5 NO3 5 TKN 87 Urea ND	NH3[b] 13 NO3[b] 5 TKN[b] 63 Urea[b] 20	NA	NR	Algal assays- no response; Periphyton- small increase in chl a but not biomass; Macroinverts- no direct change evident; Fish- no mortalities evident	By extending data collection through July 1977, Stay et al. (1979) observed changes from fertilization that were not observed through December 1976 by Stay et al. (1978); these included small increase in NO3-N in fertilized streams and differences in N-runoff between streams with 30m and 45m buffer strips. Some increases were also found in specific conductance and total cation concentrations. Algal assays using a green alga (*Selenastrum capricornutum)* indicate co-limitation by N and P. Stay et al (1979) state that co-limitation by P helped minimize algal response to added N. Invertebrate changes appeared more tied to seasonal variability than to fertlization.
Treatments - 24 sites (*Ranges indicate reported concentrations from many sites*)	NH3 5 NO3 5-10 TKN 47-100 Urea ND	NH3 11 NO3 26 TKN 2,380 Urea 8,000	NH3 no difference NO3 ~1 yr, 1-3x TKN <30 d, <1-3x Urea <30 d, ~1.5x	NR		
Location:Vancouver Island, B.C.; Application rate: 200 kg N/ha; Date: November 1979; Objectives: Effects of fertilization on water quality in streams and downstream lake; Reference: Perrin and others, 1984						
2 control streams	NH3 <4 NO3 1-27 Urea <5	NH3 15 NO3 110 Urea 20	NA	NA	NR	Lower concentrations and longer transport times observed for streams with buffer strips than no buffer strips. Cold temperatures may have caused reduced nitrification resulting in longer time for urea and NH3 to return to baseline concentrations (relative to other studies) and lower NO3 concentrations. Forest fertilization caused shift from N-limitation to P-limitation in downstream lake, & algal blooms.
12 sites on 10 streams draining 3 treatment watersheds entering a lake	NH3 <4 NO3 1-58 Urea <5	NH3 4,780 NO3 790 Urea 57,000	NH3 79-136d[d] NO3 4-84d[d] Urea 102-140d[d]	2.1–5.2%	NR	

Table 2. Summary of studies of forest fertilization effects on stream-water quality.
[Conversions: 1 kg/ha = .89 lb/ac; 1kg Urea = .46 kg N; NR, not reported;

Geographical area and streams studied	Baseline N. Conc. (ug/L)	Maximum Post-treatment Conc. (ug-N/L)	Estimated period and avg. magnitude of elevated concentration[a], vs control or baseline	% loss to streams	Biological Components studied and results	Sampling Design / Remarks
Location:Vancouver Island, B.C.; Application rate: 224 kg N/ha; Date: September 1974; Objectives: Effects of fertilization on water quality; Reference: Hetherington, 1985						
TC (Control)	NH3 0-131 NO3 0-10 Urea 0-20	NH3 61 NO3 300 Urea 540	NA	NA	NR	Previously fertilized in 1967 at 96 kg N/ha
16M (Control)	NH3 0-93 NO3 4-109 Urea 0-20	NH3 22 NO3 89 Urea 10	NA	NA	NR	Previously fertilized in 1967 at 258 kg N/ha
TF1 (Lens Creek) 40 year old plantation	NH3 0-79 NO3 7-177 Urea 0-30	NH3 540 NO3 2,700 Urea 14,000	NH3 13d NO3 >14 mos Urea 6d	5.9%	NR	No buffer strips. 46% of watershed area fertilized. Continually flowing stream. Previously fertilized in 1968 and 1972 at 258 kg N/ha. 98% of N-loss was as nitrate. Fall rains in 1975 caused increases in nitrate and urea.
TF2	NH3 0-80 NO3 28-151 Urea 0-220	NH3 1,900 NO3 9,300 Urea 790	NH3 15d[c,d] NO3 ~14 mos, ~9x Urea 14d[d]	14.5%	NR	No buffer strips. 80% of watershed area fertilized. Intermittent streamflow. Previously fertilized in 1967 at 96 kg N/ha. 92% of N-loss was as nitrate. Fall rains in 1975 caused increases in nitrate and urea. Wetlands may have contributed to higher N-loss compared to TF1.
L (Receives combined flow from both TF1 and TF2)	NH3 0-119 NO3 38-215 Urea 0-23	NH3 360 NO3 720 Urea 160	NH3 33d[d] NO3 ~14 mos[d] Urea 5d[d]	NR	NR	Located ~2km downstream from TF1. Nitrate and ammonium increases were delayed until November 1974 after 1st substantial rains.
Location: Western Washington; Application rate: 224 kg urea-N/h; Date: July 1980; Objectives: determine WQ effects of annual fertilizations; Reference: Bisson, 1982[e]						
Hook "Control"	NH3 3 NO3 262 Tot-N 113	NH3 25 NO3 268 Tot-N 488	NA	1.9-9%	NR	"Heavily fertilized w ithin 3 yrs before study" (Control)
Willow Treatment - Annual appl.	NH3 6 NO3 96 Tot-N 91	NH3 159 NO3 458 Tot-N 8,597	NH3 40 d, ~5x NO3 77d, ~1.5x Tot-N 77d, ~3x		NR	"Heavily fertilized w ithin 3 yrs before study", + applications of 65 kg/ha in 1st yr of study and annually afterwards (Treatment)
Needle "Control"	NH3 77 NO3 1,270 Tot-N 874	NH3 1,580 NO3 2,000 Tot-N 4,400	NA	NR	NR	"Heavily fertilized w ithin 3 yrs before study" (Control)
Gate Treatment - 65 kg N/ha	NH3 10 NO3 1,232 Tot-N 1,168	NH3 186 NO3 2,310 Tot-N 9,595	NH3 40 d, ~1.5x NO3 > 7 mos, ~2x Tot-N > 7 mos,~3x	NR	NR	"Heavily fertilized w ithin 3 yrs of study", + applications of 65 kg/ha in 1st yr of study and annually afterwards (Treatment). Extensive fertilization history regarded as cause of high N-export through increased nitrification.
Debris[f, g] Treatment - 224 kg N/ha	NH3 5 NO3 211 Tot-N 105	NH3 630 NO3 1,570 Tot-N 4,380		NR	NR	"Relatively little past fertilization" + application of 224 kg N/ha in 1st yr of study and annual treatment afterwards.
Eleven[f, g] Treatment - 224 kg N/ha	NH3 2 NO3 131 Tot-N 44	NH3 752 NO3 1,680 Tot-N 37,553	NH3 NO3 Tot-N	NR	NR	"Relatively little past fertilization" + application of 224 kg N/ha in 1st yr of study, and annual treatment afterwards. High Tot-N was urea from direct application. High loss may also have been due to direct application on snow.

Table 2. Summary of studies of forest fertilization effects on stream-water quality.
[Conversions: 1 kg/ha = .89 lb/ac; 1kg Urea = .46 kg N; NR, not reported;

Geographical area and streams studied	Baseline N. Conc. (ug/L)	Maximum Post-treatment Conc. (ug-N/L)	Estimated period and avg. magnitude of elevated concentration[a], vs control or baseline	% loss to streams	Biological Components studied and results	Sampling Design / Remarks
Location: Western Washington; Application rate: various; Date: various dates in 1988; Objectives: Drinking water criteria, dissolved N toxicity, and individual objectives in each basin; Reference: Bisson, 1988.						
Forks Creek [g] Treatment averaged 207 kg-N/ha, on 1/88 and 2/88	NH3 <20 NO3 30 TKN 80	NH3 40 NO3 50 TKN 160	NH3 40 d, ~2x NO3 2 d, ~1.5x TKN >30d ~2x	NR	NR	Project also tested if fertilization jeopardized water quality at downstream fish hatchery or caused algal fouling of water intake system. Sampling only for ~30 days after application
Spring Creek [g] Treatment averaged 130 kg-N/ha, on 2/88	NH3 <20 NO3 1,000 TKN 70	NH3 <20 NO3 1,500 TKN 180	NH3 no increase NO3 >30 d, ~1.5x TKN >15d, ~2x	NR	NR	Tributary to Forks Creek
Silver Lake Basin Hemlock and Sucker Creeks Treatment 92 kgN/ha (each)	NH3 20 NO3 800 TKN 300	NH3 200 NO3 800 TKN 1,500	NH3 >100d, 3-4x NO3 no increase TKN no increase	NR	NR	History of fertilizer application every ~5 yrs since 1969, water quality monitored after each application. Current fertilization in February 1988. Silver lake is eutrophic with extensive macrophyte beds.
Ryderwood, Pair 1 [g] (Campbell Creek) Treatment 92 kg N/ha	NH3 30 NO3 90 TKN 100	NH3 275 NO3 580 TKN 2,000	NH3 >100d, ~2-5x NO3 100d, ~2x TKN >100d, ~3x	NR	NR	Tributaries to Cowlitz River. No buffer strips in "treatment" watershed, "control" watershed was recent clear cut. Peak NO3 concentration in clearcut "control" was higher than in "treatment".
Ryderwood, Pair 2 (Arkansas Creek) Treatment 92 kg N/ha	NH3 20 NO3 200 TKN 100	NH3 150 NO3 600 TKN 3,750	NH3 >100d, ~3x NO3 ~75 d, ~2x TKN >100d, 2x	NR	pHs averaged 6.5-7.0, increased ~0.3 units	Paired locations on Arkansas Creek (buffered, with unbuffered tributaries); upstream=control, downstream=treatment. High TKN due to direct application
Location: Fernow Exp. Forest, W. Virginia; Application rate: 336 kg N/ha as ammonium nitrate + 224 kg P/ha as triple superphosphate[h]; Date: April 1976; Objectives: Selected water quality responses in streams, and cumulative downstream effects, tracked from 3 to 10 years; Reference: Helvey et al.. 1989, Edwards and others, 1991						
North and South Facing Watersheds	NO3 ~500 Ca 2 mg/L	NO3 ~10,000 Ca 10 mg/L	NO3 >10 yrs, >5x Ca >3 yrs, ~3x Mg >3 yrs, ~3x	N[i] 23–27% P - <1%	NR	Specific conductance increased from ~28 to 140 uS/cm in fertilized watersheds, remained high after 3 yrs, back to background after 10 yrs. After 10 yrs NO3-N remained ~40% higher than in control stream. Ca and Mg were back to background after 10 yrs except in one watershed. Average pH's in all streams were around 5.0. No apparent changes in P concentrations.
Location:Western Washington; Application rate: 224 kg N/ha; Date: various in 1988-89; Objectives: Not reported; Reference: Bisson and others, 1992						
Louse Creek (Western Cascades,2nd growth Douglas-fir.)	NH3 ~30 NO3 ~120 TKN ~100	NH3 ~800 NO3 ~1000 TKN 80,000	NH3 >30d, 5-20x NO3 >90d, 5-10x TKN ~4d, 10-100x	NR	NR	Fertilized April 1989. Virtually all of watershed's area fertilized. Studies ended after 90d, at onset of summer.
Ludwig Creek (Coast Range, 2nd growth Douglas-fir.)	NH3 ~20 NO3 ~600 TKN ~200	NH3 ~400 NO3 ~4,000 TKN 50,000	NH3 >60d, 3-10x NO3 >90d, 2-5x TKN >7d, 10-100x	NR	NR	Fertilized December 1988. Virtually all of watershed's area fertilized. Generally more protracted release of N from fertilization than Louse Creek, but Coast Range may have higher N deposition rates and nitrification rates.

a. Concentrations expressed as a relative change in the active nutrient or ingredient, per liter.
b. Concentrations reported are averages rather than maximums
c. No streamflow during fertilization at TF2. Ammonia-N and nitrate-N concentrations had peaks attributed to fertilization in October and November 1974 after rainstorms.
d. Average concentrations not reported
e. Baseline concentrations calculated from Bisson (1982) by C. Anderson, USGS, 1999.
f. Debris Creek and Eleven Creek are paired treatment watersheds, with no control watershed.
g. "Control" concentrations are baseline concentrations in the same stream prior to fertilization
h. Calcium phosphate
i. N loss of 27% includes estimated loss in groundwater

Table 3. Proposed work items and timelines for joint BLM and USGS Little River Fertilization Study, through FY02..

[Dark shading ■ indicates work items and timeframes that are currently planned. Light shading ░ indicates items that will be re-evaluated on the basis of existing data before commencing. X indicates dates for fertilization.]

Work Item	FY00												FY01												FY02												FY03											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Conduct Fertilization (Administered by BLM)														X	X																																	
Final workplan design and modification		■	■	■	■							■	■			■	■	■						■	■	■			░	░						░	░				░	░						░
Information / data infrastructure																																																
Establish & maintain streamgage(s)		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░
Establish & maintain weather/precip station			■	■																																												
Establish & maintain water quality monitor(s)							■	■	■	■	■	■	■						■	■	■	■	■	■	■						░	░	░	░	░	░	░						░	░	░	░	░	░
Stream Sampling																																																
Monthly fixed station sampling[a]	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░
Intensive fertilization sampling													■	■	■	■																																
Storm Sampling		■	■				■	■						■	■	■		■	■	■						■	■	░			░	░						░	░	░				░	░			
Select reference reaches/streams[a]		■	■	■	■						■	■	■																																			
Channel Characterization									■	■	■																																					
Stream primary production										■	■	■										■	■	■										░	░	░										░	░	░
Synoptic sampling[a]: WQ, algae, inverts(?)							■			■	■	■							■			■	■	■		■	■				░			░	░	░		░	░				░			░	░	░
Groundwater / Seep investigations						■	■				■	■	■				■	■					■	■	■					░	░				░	░											░	░
Coordinated sampling with BRD																																																
Refine and test field methods for fertilization[b]																																																
Planning	■	■									■	■																																				
Test monitors (conductivity, nutrients), isotopes	■	■	■											■	■	■																																
Automatic samplers	■	■	■											■	■	■																																
Test collectors to quantify application rate	■	■	■											■	■																																	
Assays of urea (isotopes, chemistry)								■																																								
Isotopic tracer (^{15}N)																																																
Characterize background[a]	■	■	■						■	■	■	■	■																																			
Obtain and use labelled urea		■											■	■	■																																	
Sample/analyze stream biota									■	■	■			■	■	■			■	■	■	■	■	■		░	░					░		░	░	░		░	░					░		░	░	░
Isotopic data analysis			■	■								■	■	■			■	■	■						■	■	■	■							░	░	░	░	░								░	░
GIS support Project meetings		■					■					■		■					■					■		■					■					■		■					░					
Obtain coverages for Forest Service land[c]			■																																													
Obtain coverages for private forest land				■	■																																											
Subbasin and Basin delineation				■	■																																											
Channel habitat mapping (?)												■	■	■	■	■																																
Map available WQ data				■	■							■	■											■	■										░	░												
Map geology, land use, other data			■	■	■	■	■																																									
Prepare products for publications & meetings						■	■	■										■	■							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						

/little/cwa/proposal/tab.workplan.fm

Unpublished report subject to revision. Please do not quote or release.

Table 3. Proposed work items and timelines for joint BLM and USGS Little River Fertilization Study, through FY02..

[Dark shading ■ indicates work items and timeframes that are currently planned. Light shading ░ indicates items that will be re-evaluated on the basis of existing data before commencing. X indicates dates for fertilization.]

Work Item	FY00												FY01												FY02												FY03											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Reports (incl. data analysis)[d, e]																																																
Physical setting & background WQ/algae				■	■	■																																										
Effects of fertilization: WQ																	■	■	■									■	■	■	■	■	■															
Effects of fertilization: algae																	■	■	■											■	■	■	■	■	■													
Effects of fertilization: food webs																	■	■	■															■	■	■	■	■	■									
Effects of fertilization: Cumulative																		■	■																	■	■	■	■	■	■							
Linkages between upland/streamwater																		■	■												■	■	■	■	■	■												
Synthesis report																																				■	■	■	■	■	■							
Data Report <Do we want this?>																										■	■	■	■	■	■																	
Presentations and meetings (incl. data analysis)																																																
Annual meeting: BLM/USGS/OSU				■													■	■												■	■											░	░					
Annual BLM Research Meeting											■												■												■												░	
Conferences (e.g. NABS or AGU)							■	■											■	■											■	■											░	░				
Administrative																																																
Project planning meetings (internal)		■					■					■		■					■					■		■					■					■		░					░					░
Final & Fiscal Year agreements with BLM	■	■								■												■												░														
Establish algal and(or) invertebrate contracts	■	■	■										■												■												░											
Laboratory certification and contracting[a]	■	■	■										■												■											░	░											
Project reviews, budgetting, closeout		■					■				■			■					■				■			■					■				■			░					░				░	
Hiring for intensive sampling periods[f]		■					■												■												░												░					
Data Management		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░
Training				■												■												■												░								
Establish/coordinate NRP/OSU input		■	■	■	■			■	■				■	■						■	■				░	░					░	░					░	░					░	░				

a. Already underway
b. Fertilizations are planned for fall 1999 in the Clackamas and Umpqua basins. These will be used to test sampling methods and conceptual models. If methods are successful they will be used duriong fertilization in Little River Basin in fall 2000.
c. Coverages for BLM land are already obtained and have been used for preliminary mapping.
d. Reports on individual topics will be published in refereed journals, except (possible) data report, which would be a USGS Open-file report, and (possibly) the synthesis report, which could be a Water-resources Investigations Report.
e. Final timelines for some reports will be determined upon consulation with BLM during FY01 and FY02, and may be dependent on findings to date. If BLM and USGS decide to extend sampling beyond fall FY02 based on evidence then some reports will be postponed.
f. May include graduate student from OSU.