REMOTE SENSING APPLICATIONS IN OREGON

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(E81-10014) THE APPLICATION OF REMOTELY SENSED DATA IN SUPPORT OF EMERGENCY REHABILITATION OF WILDFIRE-DAMAGE AREAS (Oregon State Univ.) 44 p HC A03/MF A01 CSCL 05B G3/43

N81-12491
Unclas
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Environmental Remote Sensing Applications Laboratory - ERSAL

OREGON STATE UNIVERSITY

THE APPLICATION OF REMOTELY SENSED DATA IN SUPPORT OF EMERGENCY REHABILITATION OF WILDFIRE-DAMAGE AREAS

ERSAL REPORT 80-1

by

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FUNDED BY:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF UNIVERSITY AFFAIRS

WASHINGTON, D.C. 20546

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ACKNOWLEDGEMENTS

Successful completion of this project would not have been possible without the support of many individuals from a number of different organizations. A special mention must be made of Lou Spink[1]: his ideas led to the organization of the project and his subsequent invaluable contributions were the result of an exceptional commitment to this effort. Many other U.S. Forest Service Personnel from the Deschutes National Forest and Region Six Headquarters provided valuable assistance. Mr. Bruce P. McCammon, hydrologist for the Deschutes National Forest, provided the ground photos used herein, and Cliff Benoit, Region Six hydrologist, provided background information useful in developing this report.

Many ERSAL staff members contributed in some way to the project, as did other Oregon State University staff. Dr. Charles Vars, Department of Economics, provided useful insights into the many economic aspects of the rehabilitation of fire damaged areas.

Project activities were funded by NASA Contract No. NGL 38-002-053.

[1] Formerly of U.S. Forest Service, Region Six Headquarters, Portland, Oregon. Presently of the Wallowa-Whitman National Forest, Baker, Oregon.

Introduction

For most people, the declaration that a forest fire has been controlled is a relief. It is a relief from concern about personal safety or property, from exhaustive efforts along firelines, or from an onerous sense of responsibility which can only be satisfied with the knowledge that the job is done. For a select few, the declaration has the opposite effect. For these persons, the task of restoring the burned area is just beginning. To them, the denuded landscape represents as large a challenge, and perhaps as much danger, as flames to the firefighter, for they know the destruction caused by the fire may not yet be finished.

The barren landscape, stripped of vegetative cover, is extremely vulnerable to heavy rains and the accompanying overland water runoff can cause loss of soil, degradation of water quality, and threats to life and property from flooding. Restoration of vegetative cover, construction of structures for drainage control, and residue treatment are among the actions which fire rehabilitation personnel must plan and implement before the first expected damaging precipitation. These immediate and short-termed actions need to be cost-effective, and must not interfere with the long-term management objectives for the area.

The requirement for timely and detailed information used to weigh the appropriateness of various action alternatives in an emergency rehabilitation effort led to the development of a cooperative effort between the U.S. Forest Service Region Six Burned Area Survey Team (BAST) and the Environmental Remote Sensing Applications Laboratory (ERSAL) at Oregon State University.

The BAST is a multidisciplinary team of resource and technical specialists available for assignment to fires of significant size or value as determined by the forest supervisor. ERSAL is a campus-based laboratory which develops practical applications for a wide range of remotely sensed data, from low-level aerial photography to satellite data.

Together, BAST and ERSAL developed and used remotely sensed data in support of the many decisions required in achieving a satisfactory rehabilitation of the burned forest land. Discussions between the USFS and ERSAL personnel began in the winter of 1979. The characteristics of the information needed for post-fire emergency rehabilitation work and the availability of various remote sensing products were reviewed. Different methods of information extraction and processing were considered and potential was seen for improving the standard sources and methods of acquiring necessary post-fire information. An agreement was reached to work cooperatively on a suitable post-fire rehabilitation project.

On July 24, 1979, embers from a neglected campfire kindled a fire on the eastern slopes of Oregon's Cascade Range within the Deschutes National Forest. Prevailing westerly winds drove flames toward the central Oregon town of Bend and blackened a portion of the city's watershed. The BAST was activated and a funding commitment for emergency rehabilitation work was received prior to control of the fire. When the fire was controlled on July 28, it had left a black scar seven miles long and one mile wide over steep terrain where highly erodible pumice/ash-derived soils were left without protective vegetative cover.

The funding commitment was based primarily on the previous identification of the area as a critical watershed because of: 1) extensive downstream capital improvements; 2) management of the area as a municipal watershed; 3) predominance of hydrophobic soil types which cause increased rates of runoff; 4) steep terrain; and 5) relatively high inherent timber productivity indices. By following procedural guidelines and policies as outlined in Forest Service Handbook 2509.13[1], the BAST prepared a Burned Areas Report (2500-8)[2] requesting $158,000. The full amount requested was awarded after a favorable review by the Chief Forester in Washington, D.C.

Pre-Fire Condition Analysis

After notification by the USFS that the fire (called the Bridge Creek Fire) area would be rehabilitated, ERSAL inventoried the available remotely sensed data. These data were then used in organizing priorities for rehabilitation actions and in supporting the requested funding commitment.

Three types of aerial photography were available: 1) high-altitude, 1:130,000 9" x 9" color infrared positives acquired by a NASA U-2 flight on August 2, 1978; 2) 9" x 18" color infrared positive transparencies at 1:32,000 acquired by NASA U-2 on August 7, 1972; and 3) black and white 1:32,000 diazo positives from original coverage contracted by the Oregon Department of Forestry. Aerial photographic interpretation of the distribution, abundance and condition of various indicator species before the burn (Volland, 1976; Franklin and Dyrness, 1973) permitted informed inferences to be drawn about such site characteristics as soil depth, texture, and water-holding capacity.

In many cases, the larger-scale CIR coverage provided enough detail for species determination and the more recently acquired small-scale CIR coverage served to update the older coverage for timber harvesting, road building, and the establishment and growth of reproduction stands during the 1972-1978 interim. The black and white diazo positives served as

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1 Burned-Area Emergency Rehabilitation Handbook, U.S. Forest Service, Washington, D.C. 1977.

2 A sample 2500-8 form in included as Appendix A. This form was designed to insure adequate collection of required background data.

inexpensive (30¢ each) copies for flight route mapping and field notes. The CIR materials were made immediately available to the BAST.

Landsat multispectral scanner (MSS) digital data were also on hand from a June 8, 1978 overflight. Processing of these data by ERSAL commenced immediately upon notification by the Forest Service of project initiation. A classification was completed 36 hours later. The satellite data provided information not readily available from other sources and the digital format eliminated time consuming planimetry required for acreage tabulations from conventional sources. These tabulations were essential to the planning and implementation phases of the project.

Most of the pre-fire condition analysis was completed prior to the declaration of control of the fire. The aerial photography was interpreted to determine type, condition and structure of vegetation. Management practices and cultural features were noted, tree species or species groups were outlined, and vegetation densities were estimated. The complexity of cover was examined, and the presence or absence of understory vegetation was determined for most forested areas. Satellite data were analyzed to develop a quantitative overview of the extent and location of various cover classes. The analysis involved the generation of grayscales to acquire required control for scaling, a classification by a minimum-distance-to-mean-classifier, and the scaling and geometric correction to a 1:24,000 scale. Interpretation of classes within the fire area resulted in the description of 19 different spectral classes in resource-related terms (Table 1). For image representations, the 19 classes were grouped to a 7 class generalization (Figure 1 and Table 2); and a digitized perimeter, from a telecopied image transmitted from fire headquarters, was subsequently imposed on completed digital materials. An overlay incorporating cultural features to aid in the location of specific ground areas on the digital

Table 1. Pre-Fire Condition Classes in Bridge Creek Fire Area.

Symbol	Acreage	Description
W	53	Mixed conifer sawlogs with a lower canopy of mountain hemlock, some lodgepole pine and other mixed conifer pole timber. Usually found on north facing slopes and upper story trees shadow the lower canopy tree crowns. The crown closure is generally > 90%.
2	322	A two story stand, very similar to the class above, "W". The canopy closure is reduced, often ≥ 70%. This class is not specific to north facing slopes, and occasional small clearings of low brush and grasses are present.
$	332	Lodgepole pine is the dominant pole timber with an overstory of occasional mixed conifers. Crown closure is often > 70% and the natural openings in this stand support brush, grass and good conifer reproduction.
/	191	A variation of the previous class "$", this represents a slight decrease in tree crown closure. Both upper and lower story have 30-40% closure. Natural openings have grass, brush and conifer reproduction.
.	460	Gentle slopes supporting predominantly lodgepole and other mixed conifer pole timber. Some sawlogs form a very scattered overstory. Natural openings of grass, small shrubs and conifer saplings are present. Overall crown closure of the site, 60-80%, is similar to the class "/", however the overstory is much reduced here.
0	312	Large clearing of conifer saplings and grass are intermixed with stands of mountain hemlock and associated conifer pole logs. Some small conifer saw timber forms an inconsistent overstory. Clearing appears both natural and, at times, man-made: skid trails are evident. Tree stands support > 80% crown closure but overall, crown closure is approximately 60%.
■	174	Commonly found on east slopes with > 80% crown closure of mixed conifers. Composition is usually small saw timber and poles (about 40-60% crown closure) over dense poles and saplings. Nearly a one story stand.
<	186	Uniform to mottled appearance with canopy closure of 70%. Lodepole pine poles and low shrubs with grass are the understory to a very scattered upper layer of mixed conifer small saw timber.
+	156	Level terrain with some evidence of select logging activity. Trees are smaller than in class "<", lodgepole pine and other conifers have 60-80% canopy closure. An occasional ponderosa pine can be observed. Shrubs and grass are present.
P	447	About 60% crown closure of mixed conifer and ponderosa pine poles and saplings. Sometimes ponderosa pine forms a scattered overstory of 10-20% crown closure. Shrubs, grasses and conifer reproduction vegetate the clearings.
N	326	Ponderosa pine and other mixed conifer sawlogs have been mechanically thinned to approximately 20% crown closure over an understory of grass, shrubs, and ponderosa pine poles and saplings. There is about 40-70% total tree cover.
H	242	A naturally thin stand of small ponderosa pine saw timber. A few other conifer species are also present to form a 40% canopy closure of all trees. Natural openings include rock outcrops, shrubs and conifer saplings.
G	593	Ponderosa pine small saw and pole timber form a 40-50% canopy closure over roughly 70% ground cover of shrubs, grasses and ponderosa pine seedlings and saplings. This class can also be 10-20% ponderosa pine pole timber over a very dense stand of conifer reproduction with a canopy closure > 80% including brush. In rare instances this may also represent 20% crown closure over a wet or moist grass-forb meadow.
V	258	The dominant vegetation is 60-70% ground cover of brush and conifer saplings. A scattered overstory of ponderosa saw and pole timber have been thinned to < 20% crown closure.
X	219	Short, gentle slopes with slash piled in rows. Occasional large pole ponderosa pine forms < 5% crown closure over shrubs, ponderosa pine saplings < 10 feet tall and grass.
*	29	Clearcuts of ponderosa pine or heavy thinning with < 10% crown closure of seed trees left. Grass, brush and conifer seedlings and saplings form 40-60% ground cover with open soil areas visible.
1	23	Light colored, disturbed and exposed soils in old ponderosa pine clearcuts. A few seed trees remain and rows of brush slash appear to be resprouting.
-	12	Ground cover of 20-30% conifer saplings, brush and/or grass with very scattered seed trees. These areas are usually in ponderosa pine.
≥	13	Very sparsely vegetated areas, only grasses and some brush. Bare soils, road scars, disturbed clearcut areas.
%	16	Unclassified.
	4,364	TOTAL

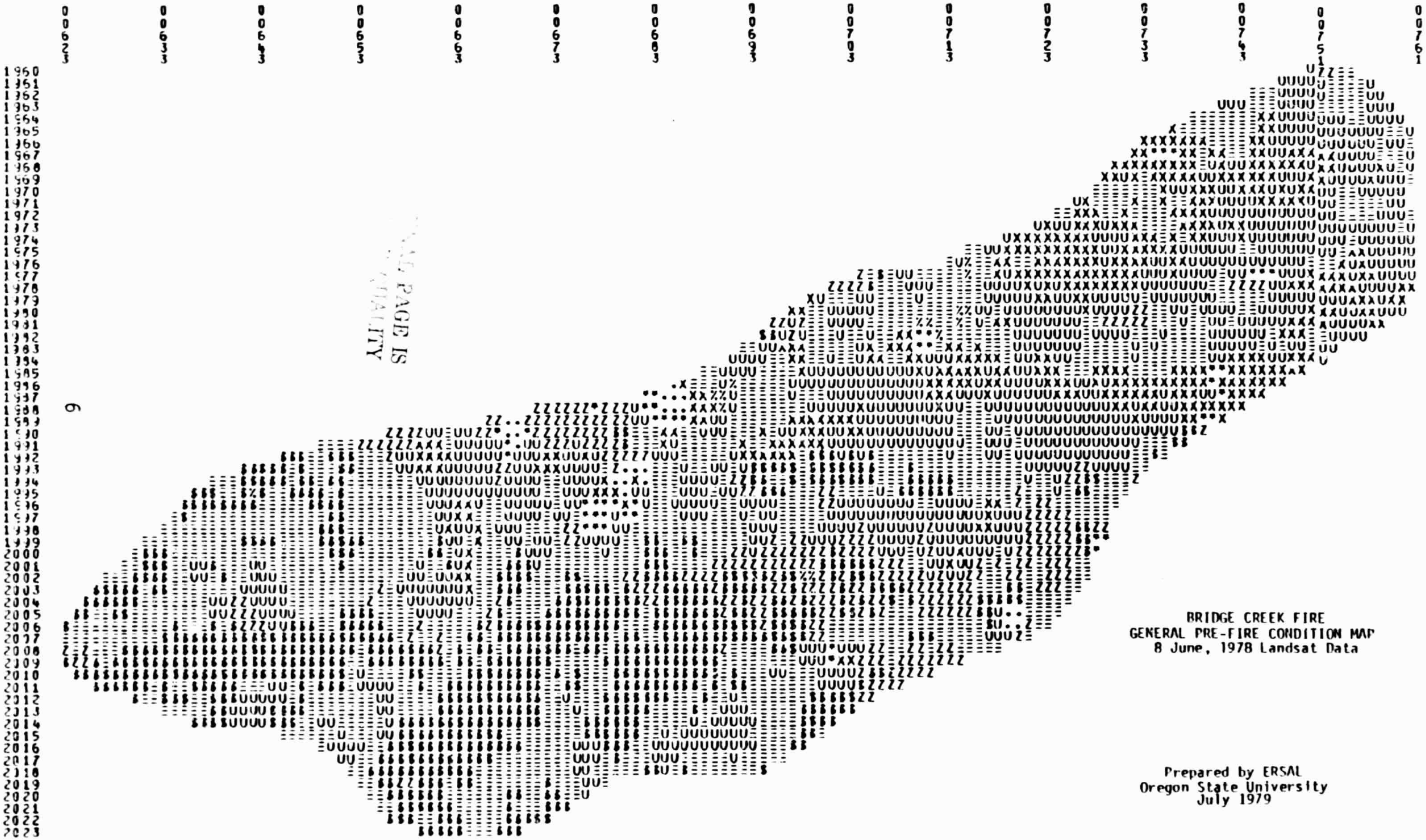

Figure 1. Digital Image of Vegetative Condition Prior to the Bridge Creek Fire.

Table 2. Acreages and Descriptions of
Generalized Bridge Creek Pre-Fire Conditions.

Symbol		Acreage	Description
$		900	Dense, mixed conifers, large and small sawlogs
■		1,389	Mixed conifer sawlogs and poles, mixed age, > 60% canopy closure.
Z		342	Lodgepole pine-dominated stands.
U		1,162	Ponderosa pine-dominated stands.
X		478	Ponderosa pine-dominated stands, moderately to heavily thinned.
*		52	Old clearcuts, young brush and trees.
.		25	Young clearcut, disturbed soils.
%		16	Unclassified.
	Total	4,364	

printout was also constructed.

Post-Fire Analysis

To obtain a detailed record on the extent and severity of the burn, photography and satellite data were acquired at the earliest possible date after control of the Bridge Creek Fire. On July 31, 1979, three days after the fire was controlled, complete coverage of the burned area was acquired on 35mm color infrared film (Figure 2). Acquired from a near vertical or low oblique perspective, these photographs were used in assessing the condition of vegetation and, in particular, for predicting likelihood of survival. Vertical natural color photography was obtained during the same flight. Negatives from this coverage were used to produce 3R prints which were in turn used to produce large-scale mosaics of the entire burned area.

As this photography was being exposed and processed, BAST crews were obtaining ground data. Guided by pre-fire condition materials, site descriptions were developed for apparently homogeneous regions within the fire. A check of cambium layer[1] damage produced an index for a wide range of fire damaged trees. Upon com, tion of the processing of post-fire photography, the ground data were used in interpreting extent and severity of damage. The specific trees whose cambium layer was ground checked were located on the infrared photographs. This was then helpful in predicting survival of trees in or near the burn (Figure 3). Ground site descriptions which appeared to represent homogeneous units on the natural color mosaic were adopted as general descriptions. Ground data which represented small or unique units were modified or disregarded accordingly. Additional ground

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[1] Inspection of the inner bark of trees reveal whether conduction of sap is occurring and permits informed guesses about likelihood of survival.

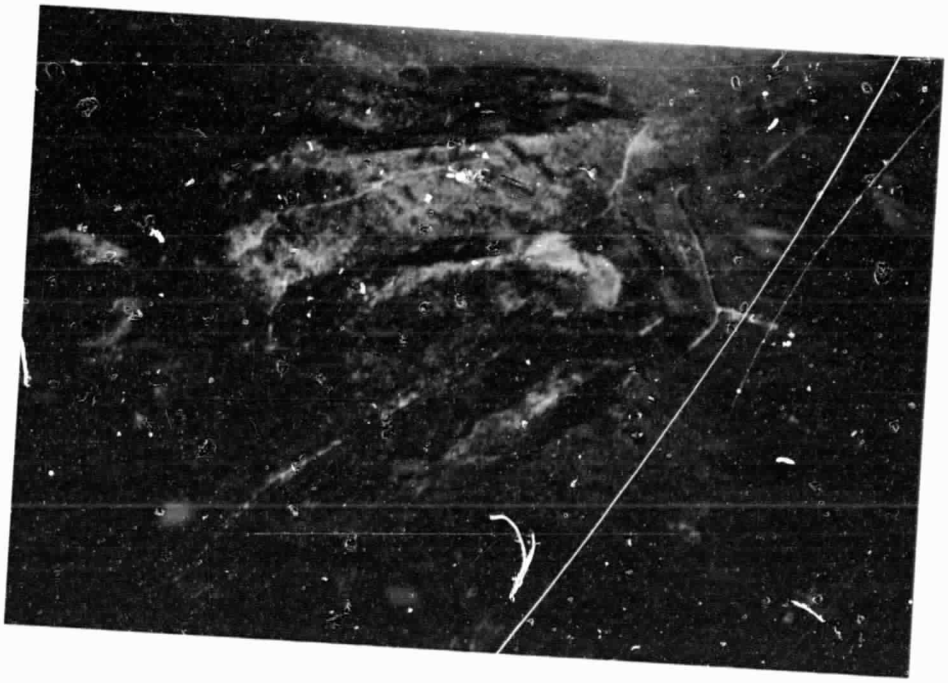

Figure 2. Oblique view of west end of Bridge Creek Fire from 35mm positive transparency original.

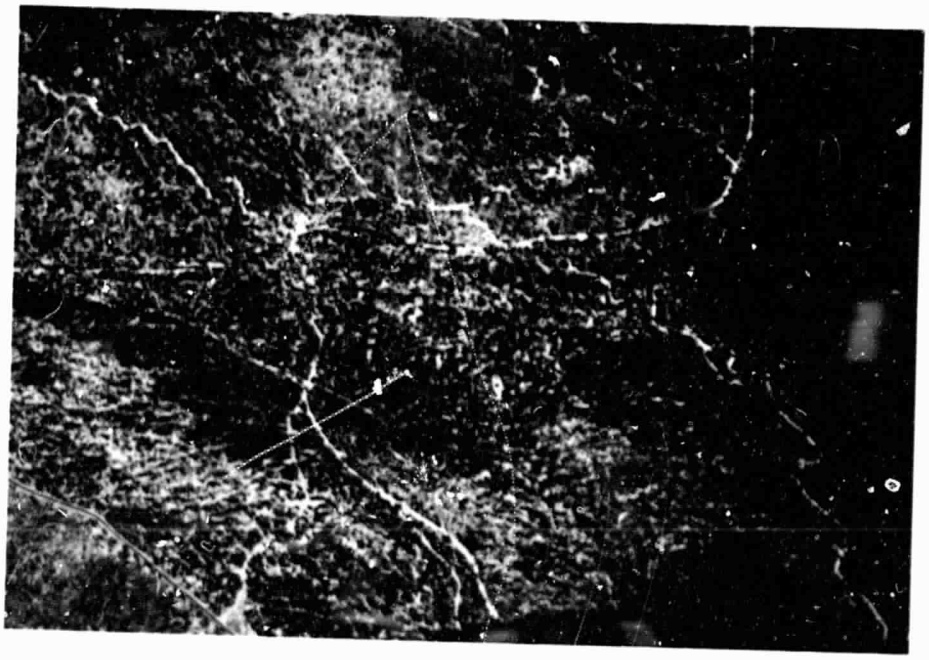

Figure 3. Likelihood of survival was predicted from 35mm color infrared photography.

data were required for homogeneous units identified on the infrared photography but for which no ground site descriptions were previously available.

To expedite the shipment and handling of Landsat data subsequent to fire control and satellite overflight, the data were pre-ordered from Integrated Satellite Information Services, Ltd. (ISIS) of Canada. On July 28, the day that the fire was brought under control, Landsat 3 passed over the burn area. MSS imagery for the evaluation of cloud cover was shipped from ISIS on July 31 and received by ERSAL on August 7. Digital MSS data for the fire area were then ordered by ERSAL on August 7 and received on August 15, less than three weeks from when the fire was controlled.

Initial data processing included the isolation of a block area from the Landsat scene that contained the fire scar. A modified unsupervised classification was performed on the block and yielded 46 classes after an initial grouping. Subsets of classes from the classification were displayed in map form, in several different combinations so that an approximation of the fire boundary could be delineated. The road network, stream courses and section boundaries were overlayed onto the classification to facilitate location. Within the fire boundary, the spectral classes were isolated and listed with their spectral characteristics.

The pre-fire classification of the area was used to verify and improve post-fire class labels. The two data sets were combined by the construction of a co-occurrence matrix (Isaacson, et al., 1979). From the matrix, significant associations between pre- and post-fire classes were identified by means of chi-square tests. The class association information was then used to modify post-fire descriptions.

The large scale, color infrared photography helped provide information on how the fire affected the vegetation. Through repeated examination of the photos, a distinct pattern (continuum) in the fire-induced alterations of the forest cover was noted (Figure 4). It was important to know how this pattern (hereafter continuum of alteration, or COA) manifested itself spectrally. With some knowledge of how stressed and unstressed vegetation reflects in the visible and near IR (reflective) portions of the electromagnetic spectrum (Figure 5), it was hypothesized that Landsat bands 7 and 5 could be ratioed to evaluate vegetative vigor. Via this rationale it was decided to refer to the spectral class list and calculate a band 7/band 5 ratio value for each class. The list of the 7/5 ratio values was compared with the photography and the classification map. It was observed that higher 7/5 ratio values coincided with the upper end of the COA (less altered) and lower 7/5 ratio values corresponded to the lower portion of the COA (greater alteration), as expected. Further analysis, through careful examination of the photography in relation to the class map, allowed the isolation of a 7/5 ratio level that represented the boundary between unaltered and altered forest land. For this particular area, an obvious numeric cut-off point occurred with a 7/5 ratio value of 0.6. Those spectral classes with a 7/5 ratio greater than 0.6 were unaltered by the fire and those with a 7/5 ratio less than 0.6 were in some way affected by the fire.

Burn classes are described and quantified in Table 3, and a post-fire image is presented as Figure 6. The total burned acreage (2778) given in Table 3 differs from total acres (4364) given in Table 2; the latter includes all of the "burn area" as initially circumscribed on a map by a Forest Service person. Not all of that area was actually burned.

Application of Results

Project results were put to use immediately. Some emergency rehabilitation work commenced utilizing crews formerly assigned to fire control

Figure 4. The Continuum of Alteration as Determined by Analysis of Landsat MSS Data.

Severity of tree damage/soil exposure. ↓

Increasing alteration.

Unaltered.

↓

Introduction of dead or damaged material with foliage intact.

↓

High proportion of dead material, foliage intact, with an introduction of dead trees with foliage consumed, some live trees.

↓

Higher proportion of trees with all foliage consumed, few live trees present.

↓

Introduction of trees with lesser branches consumed, some trees with dead foliage intact, high proportion of trees with foliage consumed.

↓

Higher proportion of trees with lesser branches consumed, introduction of some trees with most branches consumed.

↓

Higher proportion of trees with most branches consumed, some trees with all branches consumed.

↓

Most trees with all branches consumed, only dead standing stems.

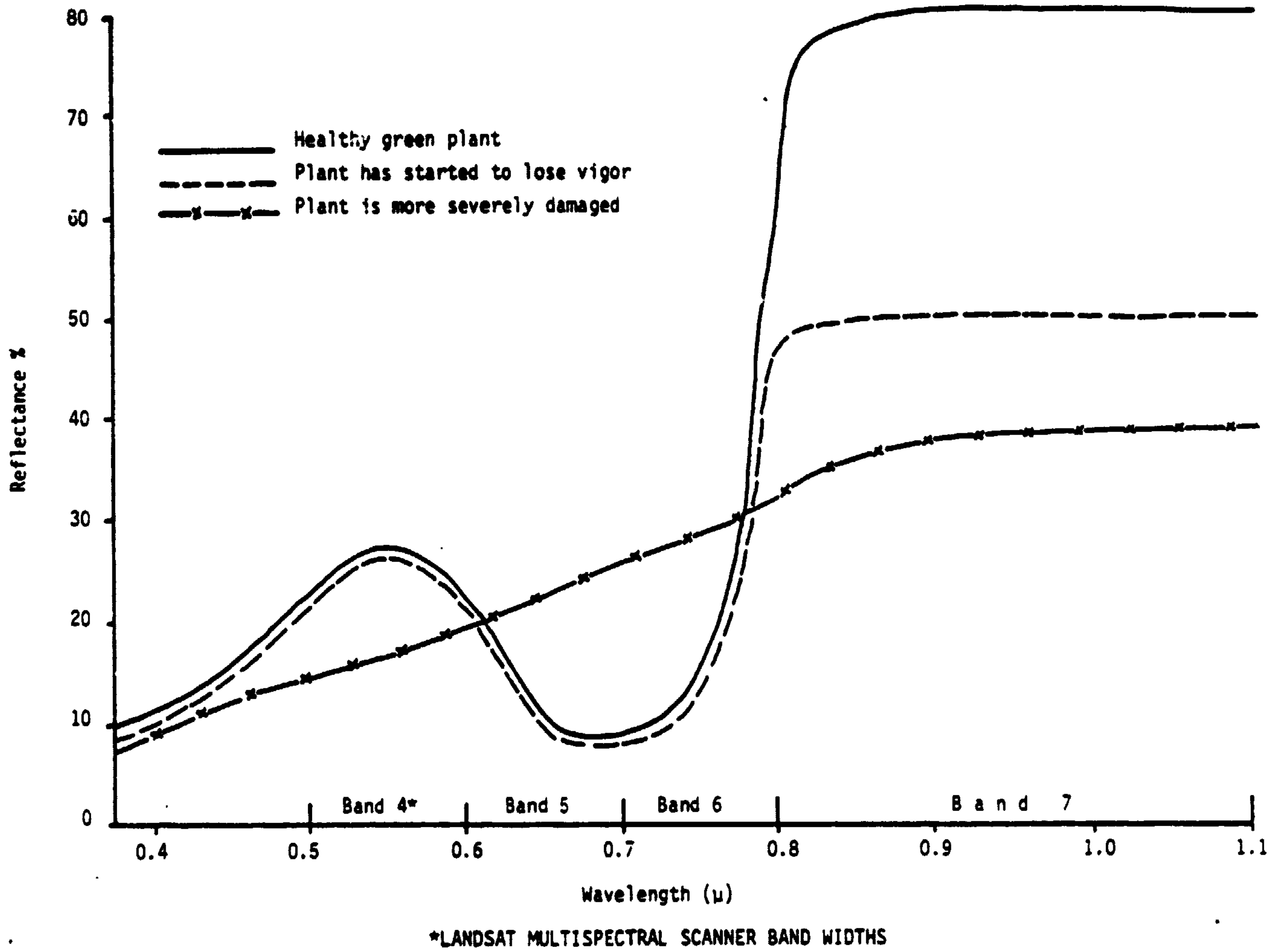

Figure 5. Condition of Plant Vigor can be Inferred from the Relationship between Reflectance and the Wavelength of Reflected Light.

Table 3. Descriptions and Acreages of Post-Fire Classes in the Bridge Creek Fire Area.

General Description	Estimated Acreage	Symbol	Estimated Acreage	Class Description
Little or no charcoal accumulation, non-vegetated areas and cultural features.	206	-	117	Low density mixed conifer and Ponderosa pine with varying degrees of fire alteration, little charcoal accumulation.
		.	89	Non-vegetated areas: rock, bare soil, some influence of road network.
Low density live standing timber with some mixing of dead standing material.	102	+	102	Low density live standing timber with some mixing of dead standing material.
Scattered standing stems with medium to low charcoal accumulation.	801	M	439	Scattered standing stems, only foliage consumed, branch structure intact, medium charcoal accumulation. Ponderosa pine origin.
		*	260	Scattered standing stems, branch structure generally lacking, medium charcoal accumulation. Ponderosa pine origin.
		/	102	Scattered standing stems, branch structure generally lacking, low charcoal accumulation. Ponderosa pine origin.
Medium to low density standing stems with a medium to low charcoal accumulation.	802	H	270	Transitional class: medium density standing stems with medium charcoal accumulation of mixed conifer origin.
		I	37	Transitional class: medium density standing stems with low charcoal accumulation, of mixed conifer origin.
		=	495	Low density standing stems, low charcoal accumulation of mixed conifer origin.
High to low density standing stems, foliage consumed, branch structure intact.	269	B	122	Dense standing stems, only foliage consumed, branch structure intact.
		O	147	Medium to low density standing stems, only foliage consumed, branch structure intact.
Dense standing stems, generally heavy charcoal accumulation.	437	W	437	Dense standing stems, generally heavy charcoal accumulation.
Areas of very heavy charcoal accumulation.	161	8	126	Areas of very heavy charcoal accumulation, originating primarily from mixed conifer and some Ponderosa pine.
		$	35	Areas of heaviest charcoal accumulation, of mixed conifer origin. Some shadowing.
Total Estimated Acreage	2,778			

Figure 6. Post-Fire Condition Map of Bridge Creek Fire Area.

duties and now available for interim work assignments before transportation to regular work stations was arranged. Some fire equipment was also immediately available for rehabilitation work. Planning for contract labor and specialized tasks was also initiated immediately upon control of the fire. Since the Bridge Creek Fire site lies within a zone where summer thunderstorms are common, there was no time to waste in completing the required rehabilitation work before the first damaging rainfall. Information essential to the planning and direction of this work had to be supplied quickly. Some examples of the uses of project results are cited in this section.

Many standing dead snags were left after the fire. Where logging methods compatible with a minimal disturbance of soils could be employed, considerable volumes of marketable wood were found to be salvageable. In some areas snags represented potential hazards, as material for stream jamming and subsequent flooding, or as waterborne debris which would damage control impoundments or downstream capital improvements. In other areas, snags were used as the primary material for contour terracing (Figure 7). Areas with standing dead snags were easily located on natural color 35mm 3R prints. By examining topographic relief on USGS quadrangle sheets, the species composition on pre-fire photography and satellite digital images, and the extent of homogeneous areas on the images, plans were made for logging, snag falling, and snag removal. Salvage sale units for logging snags by helicopter (Figure 8) were delineated. Assignment of snag-falling crews of a size appropriate to the area to be treated were made. Areas along channels where snags and debris showed a potential for jamming were located. The material was then burned or otherwise removed. The combined use of pre- and post-fire condition information and topography, along with the ability to quantify the areal extent of homogeneous areas,

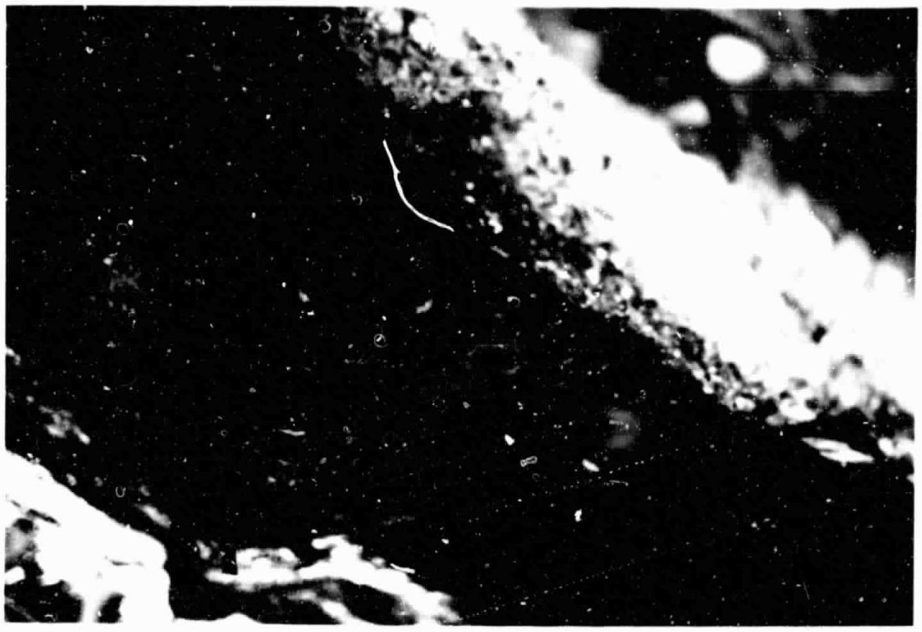

Figure 7A. On very steep slopes, snags were anchored or pinned in place to intercept silt and debris.

Figure 7B. On long slopes where large volumes of water could be predicted to move overland, snags were felled parallel to contours to break up flow and collect silt deposits.

Figure 8. Helicopter logging permitted recovery of salvageable wood with minimum disturbance of soils.

permitted quick and efficient planning and allocation of the work effort in snag treatment.

The seeding of grasses was required on most sites which had burned with a high intensity. In general, this type of burn occurred within dense stands, most of which had been comprised of mixed conifer. To identify and quantify the extent of areas to be seeded, the pre-fire digital image was used as the primary information source. By studying acreage tabulations for the pre-fire condition, estimates of grass-seeding acreages were calculated and used in contracting for custom helicopter seeding (Figure 9). Seeding of 1,600 burned acres, under a federal contract, commenced eight days after control of the fire. Where feasible and necessary, irrigation was applied to insure adequate germination and establishment of the grasses (Figure 10).

In addition to seeding of grasses for quick protective cover, considerations must be given to the variety of grass species available for use. Where the land is to be restored to timber production, annual grasses are used to minimize grass competition with newly-established trees. Perennial grasses, which would limit reforestation success, are used on sites where other uses are planned. Since pre-fire vegetation patterns imply site capability for timber production, project information was utilized to decide which grass species to employ.

Construction of basins to capture larger volumes of silt and debris than could be held by the snag terraces was required along natural dissections in topography. The siting of these impoundments (Figure 11) was aided by the use of materials mentioned above. The assignment of crews and caterpillars required in impoundment construction was made more efficient by previously determining the number and location of areas where such basins needed to be located.

Figure 9. Aerial seeding of grasses by helicopter was accomplished on 1,600 burned acres to stabilize soils.

Figure 10A. Irrigation water from Bridge and Tumalo Creeks was applied where feasible to insure germination and establishment of seeded grasses.

Figure 10B. By September, vigorous stands of grass had been established from seeding operations.

Figure 11. A caterpillar-constructed debris basin placed to intercept large volumes of silt and debris. Original depth of this basin was 4½ feet.

While examples such as those mentioned above serve to illustrate how project information supported specific on-site emergency rehabilitation activities, a special comment must be made about the many decisions made during the relatively short period of time when action is regarded as "emergency" in nature. Some of these decisions may have extremely adverse impacts upon future management options if they are incorrect. An example is provided from the hot, moderate or light burn intensity decision. Those areas recognized as hot-burned were designated as critical areas. The immediate concern regarding these hot-burned areas is the prevention of soil erosion. The first mapping of burn intensities by direct observation (mostly on foot) was not sufficient to identify all areas that required the critical area treatment. Only with the availability of post-fire aerial photography were all heavily burned areas recognized. The acreage of these areas was quantified by comparison to the Landsat based vegetation map. On a hot-burned area the fire has consumed the ground vegetation and litter layer thus exposing the mineral soil surface. The top one to three inches of this surface is naturally water repellant, with the repellancy increasing with depth. This surface is highly susceptible to overland flow from surrounding areas. Grass seeding with fertilizer helps to decrease the problems associated with repellancy. Annual grass species are used to achieve a vegetation cover in the shortest time possible both in the same season and the following spring. A square mile of high erosion hazard area that receives a hot burn can be expected to give up 6000 cubic yards of top soil per year. If treated by seeding, this loss is reduced to 2700 cubic yards of erosion per square mile. The results of failure to recognize a critical area can be immediate if a summer thunder storm follows the burn. To reiterate, there are many decisions made within a restricted budget and time frame which carry long-term consequences with both positive and negative potential.

Damage Averted

A series of potentially damaging thunderstorms passed over the Bridge Creek Fire area during the late summer and fall of 1979. Most notable of these was a storm occurring on October 19, 1979, 83 days after the fire. Four-tenths inches of rain fell in 15 minutes during this storm, and nine-tenths inches within 7½ hours. These rates and amounts were equivalent to a 6-year storm, however no damage was recorded. At the Bend municipal water intake the only measurable effect of the storm was a slight increase in suspended ash particulates, which was not considered signficiant. Most debris basins filled to capcity but none were broached (see Figure 11). Many contour snag terraces filled to capacity and diversions of flows were successful in avoiding significant damage to trails, roads and other improvements (Figure 12). By the time of the storm, most grass seedings had established sufficiently to protect the soil surface. In short, completion of all emergency actions was accomplished in time to avert any significant damage even though these measures were tested by near-maximum precipitation rates and amounts for which the erosion control structures were designed. Post-storm inspection revealed that nearly all actions had been severely tested and were "just barely" sufficient. This is evidence of correct planning and implementation for specifications without wasteful overexpenditure of effort and resources.

The expenditure of $163,000[1] for emergency rehabilitation of this burn is quite modest in comparison to the total hazard potential of $25,017,146 calculated by the BAST. This value is calculated from evaluations

[1] $158,000 requested by BAST plus $5,000 expended by ERSAL.

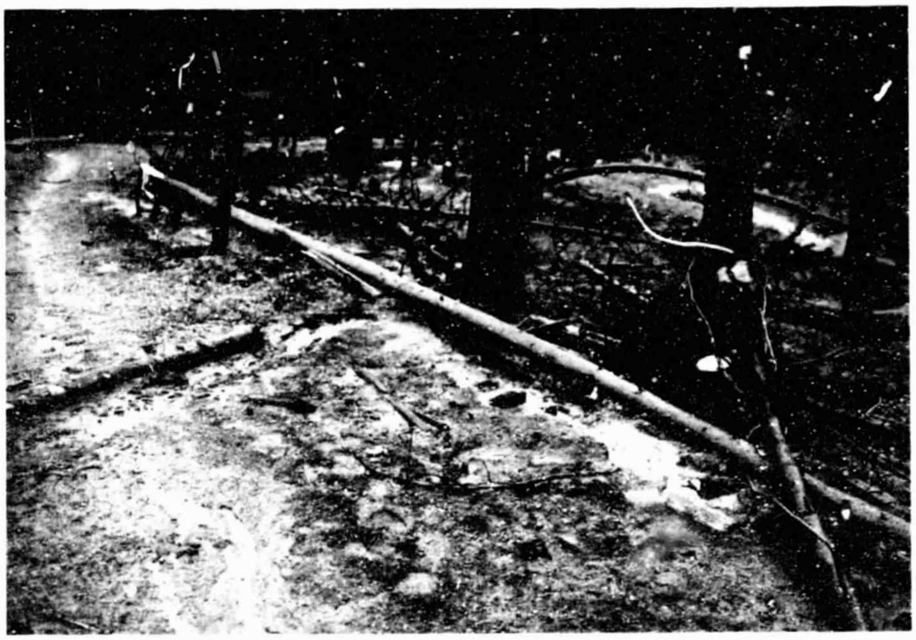

Figure 12. Diversions along roads and trails prevented damage by channeling.

of resources at risk and include such items as transportation systems, water distribution systems, agricultural development, and fish habitat. Examples of failure are available to illustrate the consequences that may result in the absence of a successful, modestly funded rehabilitation effort. The Crum Canyon Fire in eastern Washington in July, 1976 burned 9,000 acres. Although this is a larger area than the Bridge Creek Fire, it involved less erodible soils (in terms of both acreage extent and soil characteristics)[1]. Rehabilitation efforts failed when a high-intensity thunderstorm struck eleven months after the fire. Cost of subsequent rehabilitation efforts totaled nearly $1 million, and total losses exceeded $18 million. Seventy-six percent of the downstream capital developments were destroyed in the resulting flood. A similar loss level in the Bridge Creek area could be even greater. While comparisons between these two fires is difficult because of widely different circumstances, the point to be made is that a relatively modest investment in a successful emergency rehabilitation program avoids losses which may amount to sums orders of magnitude greater. Timely and accurate information, much of it derived from remotely sensed data, greatly enhances the likelihood of a successful rehabilitation project. A summary of BAST and ERSAL activities, and the role of remote sensing in decision making is provided in Table 4.

Economic Considerations

In evaluating the utility of remotely sensed data as a source of information for post-fire emergency actions, the most desirable end result would be a precise statement of the net value or an accurate benefit:cost

[1] Crum Canyon Emergency Rehabilitation Report, Entiat Ranger District, Wenatchee National Forest, December, 1976.

Table 4. Chronology of BAST and ERSAL Activities.

Day of Fire	Decision/Action	Information Needed	Information Source
1 (7/24/79)	rehabilitate/notify ERSAL	location of fire	direct observation
	gather existing information	resources prior to fire; long term management plans	Forest Supervisor's Office (S.O.)
	begin mapping at ERSAL*	vegetation type, location, acreages	1:130,000 CIR; Landsat MSS CCT's
2	continue vegetation mapping*	vegetation type, location, acreages	1:130,000 CIR; Landsat MSS CCT's
	go to fire		
	begin mapping burn	Hot, Moderate, Light (H, M, L) burn in relation to slope, soils, forest type (site potential)	direct observation forest type map
3 & 4	continue and complete* mapping tasks; deliver vegetation cover map*		
5	fire was controlled; estimate rehabilitation costs**	notice of control and final fire boundary; probable rehabilitation activities	Fire Boss; H, M, L and slope in relation to mapped acreages of pre-fire vegetation (Landsat) and site potential
6	prepare contracts for seedings and fertilizer applications**	site and location of areas to be treated; long term management plans for treatment areas	pre-fire vegetation map (Landsat); H, M, L and slope mapping; management plans
7	prepare and submit application for rehabilitation funding	identify hazards created by the fire; estimated rehabilitation costs	prior knowledge of values at risk; probable rehabilitation activities
	acquire 35mm aerial photography*	burned area boundaries	USFS
8	catalog, label and deliver new aerial photos*		
	received approval for rehabilitation funding		USFS Headquarters
	begin interpretation of post-fire aerial photography		
9, 10, 11	revise delineation of treatment areas**	corrected H, M, L mapping	35mm aerial photography
	adjust seeding cost estimates**	revised delineation and acreage of treament areas	corrected H, M, L mapping
	apply for additional rehabilitation funds	adjusted seeding cost estimates	revised treatment areas
	adjust seeding contracts**	revised treatment areas	35mm aerial photography
	designate trees to be left for seed source**	trees with sufficient prediction of survival	35mm aerial photography and spot checks of cambium damage
***	designate area for salvage logging**	homogeneous areas of snags and acreages	35mm aerial photography, pre-fire vegetation map (Landsat) and field checks

* activity accomplished by ERSAL staff; all other activities were accomplished by BAST members

** decisions and actions to which information extracted from remotely sensed data had a direct application

*** rehabilitation efforts continue at the forest level; however BAST activities, and therefore its utilization of remotely sensed data, were concluded by this time ratio. Unfortunately, because of several complicating factors, such results are not possible. One factor to be considered is that information other than remotely sensed data is incorporated. Other information sources are required just to use remote sensing data. The use of all available pertinent data sources provides an integrated base of information which does not permit dissection into discrete subunits. Another complicating factor is the dynamic influence of timeliness upon the value of information. As supervisors and managers are evaluating, planning and implementing treatment actions, time constraints are imposed such that decisions will be made based on information available at the time. If remote sensing-based information is available before the time of a decision, it has high utility; otherwise it is useful only if subsequent actions can be adjusted. As an example, in this project, color infrared post-fire photography was available only after return from processing at Kodak's Rochester, NY facility, which required about 10 days. This photography would have been much more valuable if it had been immediately available.

Because of complicating factors inherent in a comprehensive economic review and analysis of the utility of the application of remotely sensed data, this section presents a brief, but revealing analysis which will show that such an application was a good investment.

The costs of using the remotely sensed data, including acquisition, analysis, production and some consulting was less than $5,000[1]. This included some development costs related to the post-fire analysis of Landsat MSS data, which were not used, but $5,000 will be assumed to be project costs for remote sensing in order to maintain a conservative approach.

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1 For those who can be satisfied with an intuitive view of the utility of the use of remotely sensed data, $5,000 is slightly more than 3% of all emergency rehabilitation expenditures. Many firms and public agencies expend more than this to acquire information for <u>routine</u> operations without a restrictive requirement for timeliness.

It is further assumed that the project was conducted within the milieu represented in Figure 13. That is, benefits of the overall project are expected to outweigh costs but will be less than total potential benefits. Benefits attributable to specific actions can be viewed within the context of how much additional benefit is derived from using one method over another (2 over 1, Figure 14). Only one specific example will be quantified here but several others could be developed, each with positive results for improved information.

This example involves the superiority of the Landsat MSS image over a conventional information source used by the U.S. Forest Service, the "stand exam". Upon delivery of the Landsat digital image depicting pre-fire condition to one of the BAST members, a discrepancy was noticed with respect to stand composition at a location west of the confluence of the two major streams within the burn. While this entire region was recorded as a mosaic of mixed conifer types on the stand exams, 36 pixels on the Landsat image were denoted as pine-dominated stands. The existence of pines before the fire implied drier site conditions and perhaps some susceptibility to fire from lightning because the site was higher than surrounding areas. This area, approximately 40 acres, was large enough to be considered a "treatment opportunity", defined as a homogeneous unit exceeding a certain minimum size and worthy of specific management plans and goals. Because of the discrepancy, the BAST member assigned a ground crew to check site conditions to determine which information source was correct and whether the area should be considered a unique treatment opportunity within the surrounding mixed conifer zone. The area was subsequently confirmed to have been pine-dominated and distinct from the surrounding area.

Consideration of the consequences of actions based on erroneous

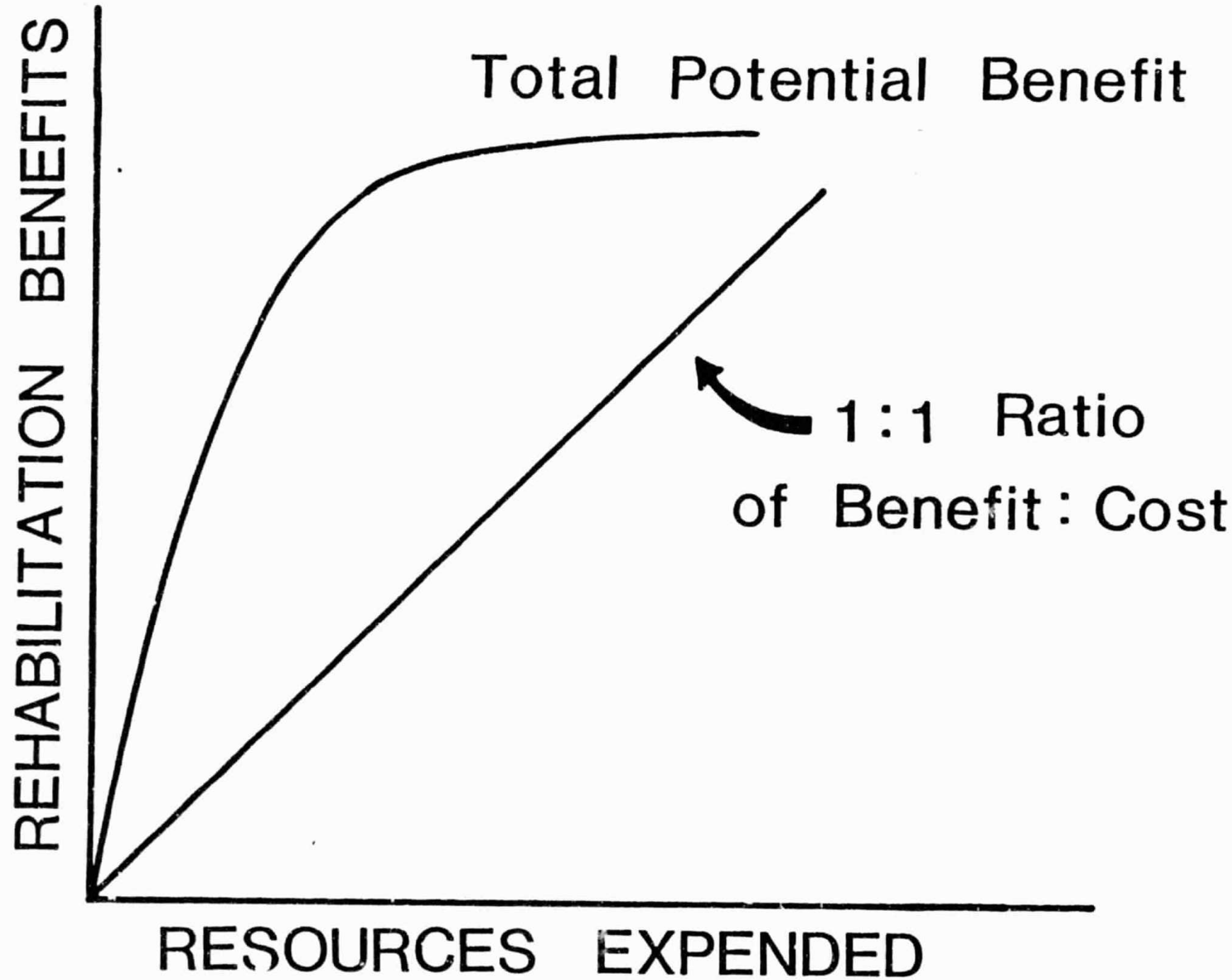

Figure 13. Expected Benefits of Emergency Rehabilitation Efforts are Expected to Exceed Costs, but Will be Less Than Total Potential Benefit.

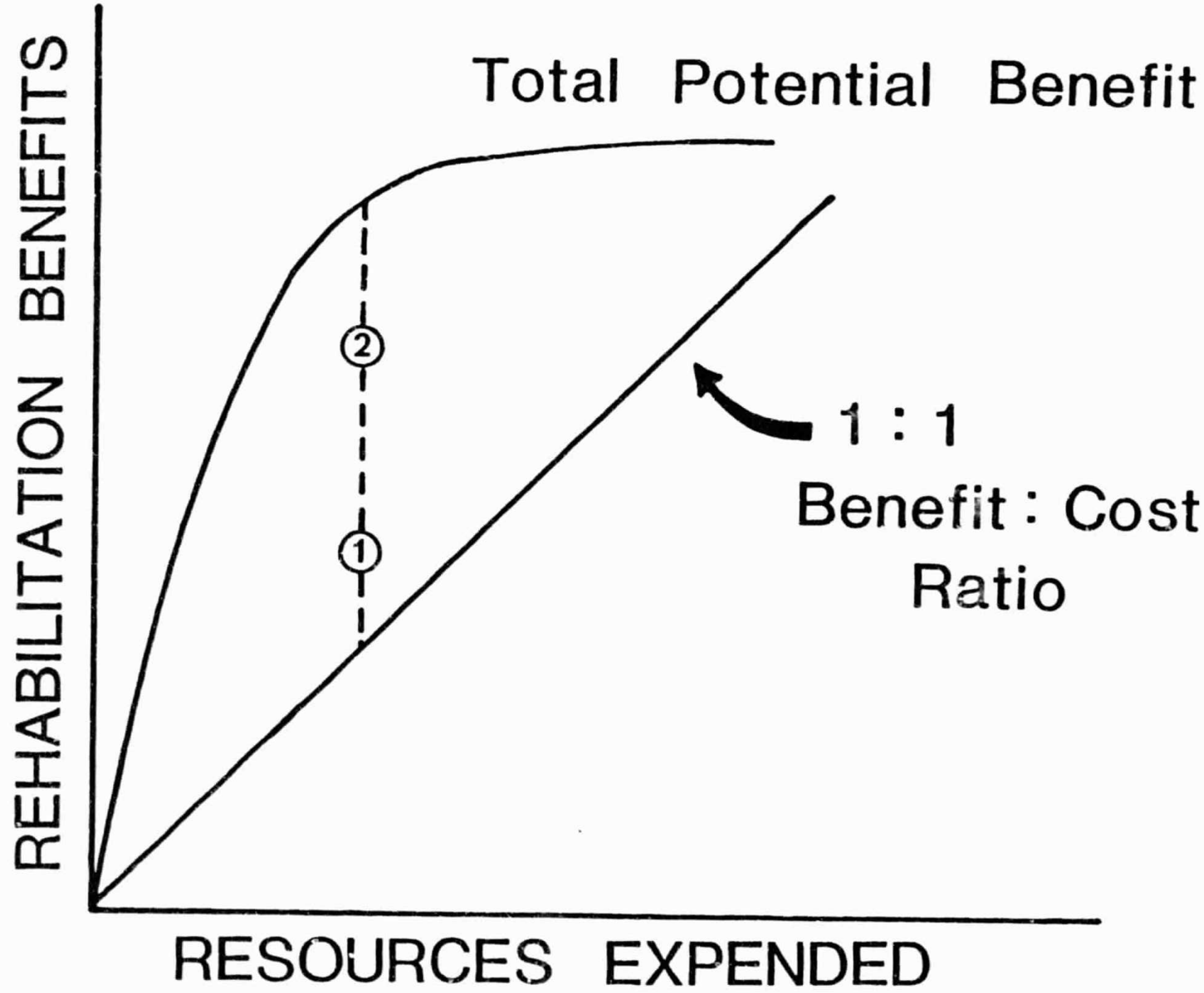

Figure 14. The Question of How Much Utility can be Attributed to Remote Sensing Applications to the Bridge Creek Fire is Addressed by Comparing the Relative Benefits from Use of Various Information Sources.

information sources permits the development of estimates of economic impact. The most likely scenario, and the best case, is that mixed-conifer species would be planted or seeded and a failed reforestation effort would be evident in two to three years. In evaluating the site, failure would be attributed to site characteristics inappropriate to the species used. This would be corrected by planting or seeding again, this time with pine species. The primary loss, in this instance, is the cost of an additional reforestation effort, at $280-440[1] per acre costing $11,200-17,600. Secondary losses include three to four years unrealized growth and the expenses of further site evaluation and planning. Worse scenarios, not at all implausible, can be developed. Failed establishment on 40 acres within a large matrix all managed for mixed-conifer may not be noticed at all, and decades might pass with 40 acres remaining in an unproductive state. Marginal establishment of mixed-conifers might be realized only to be destroyed later by fire while pines would have sustained less damage, since pine is a fire-tolerant species.

In this single instance, avoidance of an error which would have been committed had conventional information sources been used, the benefits exceed costs of the entire range of remote sensing-related activities. While this example illustrates conclusively the worth of accurate information, it is not isolated and fortuitous. In reforestation considerations alone, BAST members are faced with a complex framework of decisions, and errors may have extremely adverse consequences. Figure 15 is a simplified diagram presenting only the first few decision levels facing BAST members. Each of the decision levels was represented in this project and supported

[1] Bridge Creek Fire Rehabilitation Report, U.S. Forest Service Region 6, August 21, 1979.

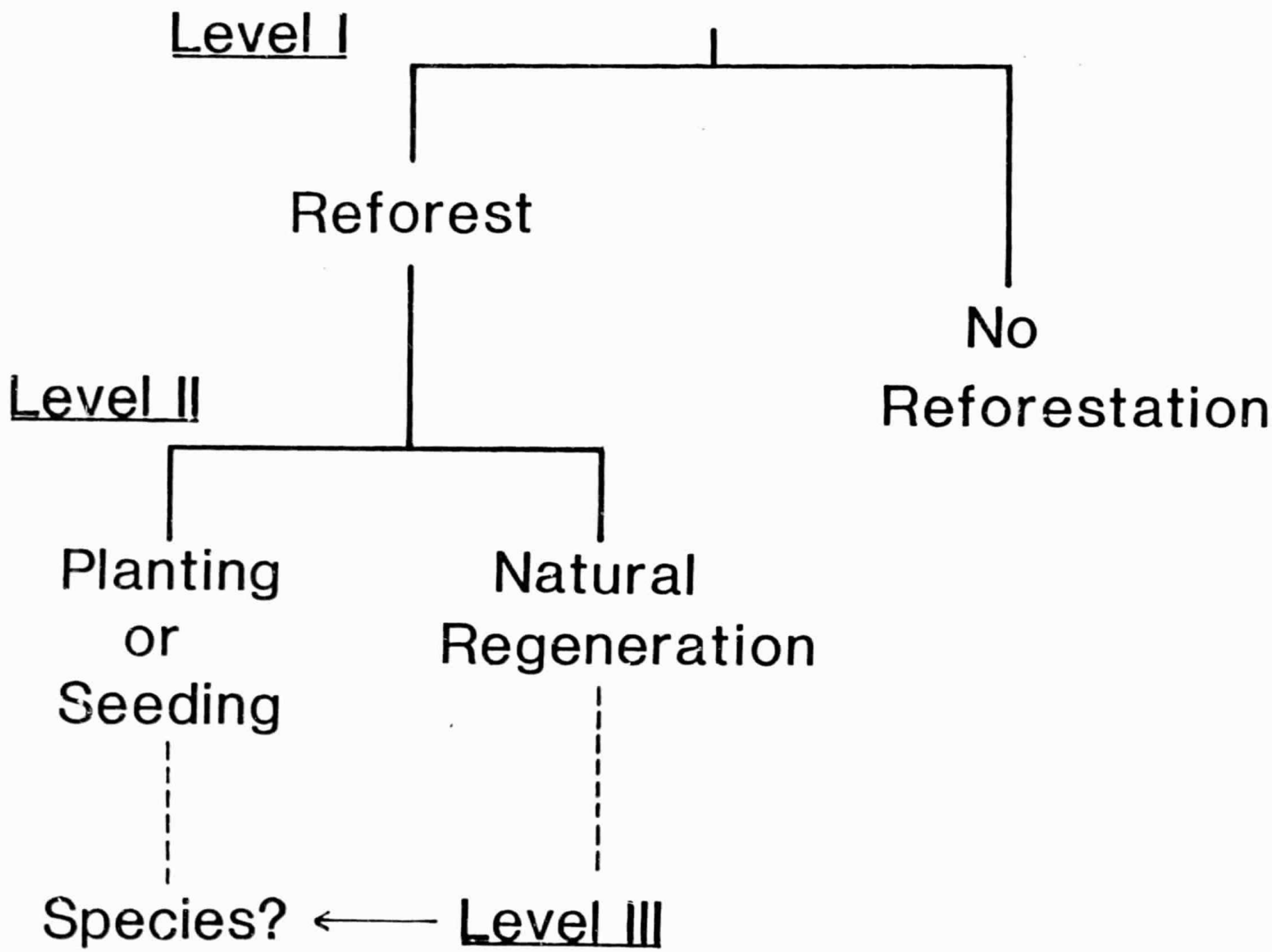

Figure 15. Simplified Representation of Initial Decisions Required in Reforestation Planning.

by timely and accurate information in such a way that errors were much less likely.

Final Notes

Final mention must be made of the potential of utilizing techniques developed and experience gained in this project on other emergency projects.

First, as with any new project, a number of improvements could be affected which would reduce costs or improve timeliness or quality of remotely sensed data. For example, at the time of acquisition of post-fire 35mm photography, processing alternatives for CIR film were thought to be limited to either the 10-14 day service at Kodak's Rochester, NY facility, or quicker local custom processing at a higher cost. In retrospect, $75 or $100 , even for processing just one or two rolls of 35mm film, seems a bargain given that there is an immediate need for CIR in the first few days after control of a fire. Subsequent queries have resulted in the discovery of sources of services which make possible the provision of 70mm CIR post-fire coverage at reasonable rates available within hours. Several other improvements could now be made based upon the experience gained from the Bridge Creek Fire Project.

Finally, post-fire Landsat digital data were not used in supporting decisions on this project because the interval between acquisition and delivery was so great. However, post-fire data does have considerable potential in other post-fire projects. At Oregon latitudes, assuming two functional Landsats, coverage for any region on the ground can be obtained within an eight-day interval from the day a fire is declared controlled. With satisfactory arrangements, considerable improvement can be made in shortening the interval from acquisition to delivery.

Assuming improved services from ISIS, Ltd. of Canada, it would be possible to use post-fire MSS data on large fires such as those that occurred in Idaho[1] during the summer of 1979. In such circumstances Landsat will likely be the only available data source which offers both comprehensive coverage and satisfactory detail. Development of simple and quickly applied techniques such as the 7/5 band ratioing capability reported here make an invaluable source of information available to BAST members working on huge rehabilitation projects such as the Mortar Creek Fire, which was more than 10 times the area of the Bridge Creek Fire.

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[1] Mortar Creek Fire, Idaho

Selected References

Colwell, R.N. 1977. Some Basic Considerations in Remote Sensing. University of California, Berkeley, Department of Forestry and Conservation, p. 1-183.

Franklin, Jerry F. and C.T. Dyrness. 1973. Natural Vegetation of Oregon and Washington. Pacific Northwest Forest and Range Experiment Station.

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Volland, Leonard A. 1976. Plant Communities of the Central Oregon Pumice Zone. U.S.D.A. Forest Service, Pacific Northwest Region, Region 6 Area Guide 4-2.

Exhibit 1

BURNED AREA REPORT

Specific instructions for use of this form are attached. Overall instructions are in FSM 2523 and FSH 2509.13, Burned-Area Emergency Rehabilitation Handbook.

1. Fire name	2. Request ☐Initial ☐Interim ☐Final Accomplishment report ☐FFF ☐Other	3. Date of report

4. State	5. County	6. Congressional District	7. Region	8. Forest	9. Ranger District

10. Supervisor fire no.	11. Date fire started	12. Date controlled	13. Estimated suppression cost $

14. Fire suppression damages repaired with FFF 102 funds mi. firelines waterbarred acres firelines seeded
15. Fuel type fire intensity % light % moderate % extreme

NATIONAL FOREST SYSTEM PROBLEM INVENTORY

16. Watershed no.	17. NFS acres burned	18. Water repellant soil % of NFS area burned
19. Vegetation types		
20. Geologic types		
21. Soil erosion hazard rating	22. Erosion potential cu. yds./sq. mi.	23. Storm peak potential cu. ft./sec./sq. mi.
24. Miles of stream channels by Regional order or classes		
25. Miles of Forest Service roads by maintenance levels mi. level I mi. level II mi. levels III, IV, V		

CLIMATIC DATA

26. Annual precipitation inches	27. Design storm rainfall during _____ hour period inches 2 yr. frequency inches 10 yr. frequency
28. Annual runoff inches	29. Maximum 30 minute intensity storm inches 2 yr. frequency inches 10 yr. frequency

SUMMARY OF SURVEY AND ANALYSIS

30. Skills represented on burned area survey team (check) ☐Hydrology ☐Soils ☐Geology ☐Range ☐Timber ☐Wildlife ☐Fire Management ☐Engineering ☐Contracting ☐Local Management ☐Research		
31. Describe emergency		
32. Emergency rehabilitation objective		
33. Personnel needs for rehabilitation project on NFS lands man-years reassigned for $ man-years new hires for $		
34. Probability of completing treatment prior to first major damage-producing storm Land % Channel % Roads % Other %		
35. Net environmental quality benefit index ☐Significant ☐Not Significant	36. Net social wellbeing benefit index ☐Significant ☐Not Significant	
37. Benefit/cost ratio	38. Cost effectiveness index (check one) ☐I ☐II ☐III ☐IV	
39. Forest Supervisor approval & date	Regional Forester approval & date	Date funding approved in WO

2500-8 (5/76)

Exhibit 1 -- Continued

USDA - Forest Service

BURNED AREA REPORT

Fire Name

Date of Report

ON-SITE AND OFF-SITE DEVELOPMENTS SUBJECT TO HAZARDS FROM FLOODS, FLOATING DEBRIS, EROSION, OR SEDIMENT BECAUSE A WATERSHED IS IMPAIRED BY WILDFIRE. (Do not include value of resources damaged or destroyed by the fire as reported on Form 5100-29.)

	No. of units	Estimated value (dollars)
40. Community and urban development	people	
41. Municipal water supply	people served	
42. Transportation systems	miles	
43. Water distribution systems (irrigation)	miles	
44. Agricultural development (crops, facilities)	acres	
45. Industrial development (dams, power, manufacturing)	number	
46. Power and communication lines	miles	
47. Recreation development	PAOT	
48. Fish habitat	miles	
49. Other (specify)		
TOTAL HAZARD POTENTIAL		

SUMMARY OF EMERGENCY REHABILITATION NEEDS BY LAND OWNERSHIP

Land ownership	50. Acres burned	51. Emergency rehab needs Land acres	Channel miles	Road miles	Other	Source of emergency rehabilitation funds for needed work (dollars) 52 FFF	53 216	54 FR&T	55 Other Fed. (Name)	56 Non-Fed. (Name)	57 Total
FEDERAL NFS											
Other (name)											
Subtotal											
NON-FEDERAL State and county											
Private											
Indian											
Subtotal											
TOTAL											

2500-8 (5/76)

Exhibit 1 -- Continued

USDA-Forest Service

BURNED AREA REPORT

Fire Name Date of Report

ELIGIBLE EMERGENCY REHABILITATION MEASURES OR TREATMENTS AND SOURCE OF FUNDS
(Emergency rehabilitation is work done promptly following a wildfire and is not to solve watershed problems that existed prior to the wildfire.)

			NFS Lands			Other Lands			Total dollars all lands
	Units	Unit cost	No. of units NFS	FFF 094 dollars	Other dollars (Name)	No. of units other	Federal dollars (Name)	Non-Fed. dollars (Name)	
58. LAND									
Seeding	Acres								
59. CHANNELS									
Opening water courses	Miles								
Stabilizing streambanks	Miles								
60. ROADS									
Ditch cleaning	Miles								
61. MAJOR STRUCTURES									
Preplanned structures from Unit Plans	Each								
		TOTAL							

USDA-Forest Service
Fire Name

BURNED AREA REPORT

Date of Report

EXAMINING IMPACTS OF MANAGEMENT ALTERNATIVES FOR AN EMERGENCY PROGRAM

62. ECONOMIC BENEFITS SUMMARY WITH ____ PERCENT INTEREST RATE

ECONOMIC CRITERIA	Units of measure	Without treatment		With treatment		Difference in present value $
		No. of units	Present value $	No. of units	Present value $	
SEDIMENTATION IMPACTS						
Downstream storage						
Sediment removal						
Fish habitat						
Water quality						
FLOOD WATER DAMAGE						
Land						
Property						
OTHER						
TOTAL DOLLARS						

63. ENVIRONMENTAL QUALITY BENEFIT INDEX

ENVIRONMENTAL CRITERIA	Weight Factor	Without treatment		With treatment		Difference	
		Actual	Weighted	Actual	Weighted	Actual	Weighted
Erosion and sediment							
Aesthetic land quality							
Water quality							
Ecological benefits							
Fish & wildlife habitat							
Other							
TOTAL							
Average weighted index							
Net environmental quality benefit index							

64. SOCIAL WELLBEING BENEFIT INDEX

SOCIAL CRITERIA	Weight Factor	Without treatment		With treatment		Difference	
		Actual	Weighted	Actual	Weighted	Actual	Weighted
Life, health, safety							
Employment							
Recreational opportunity							
Economic stability							
Income distribution							
Preserve special sites							
Other							
TOTAL							
Average weighted index							
Net social wellbeing benefit index							

2500-8 (5/76)