Use of Cumulative Effects Assessments in Determing the Impacts Of Herbicide Application Programs on Water Quality

Daniel G. Neary[1]

Cumulative effects or impacts are defined in the Code of Federal Regulation (1971) as:

> "*the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time*."

Cumulative effects analyses offer a broader approach to the issue of water quality since they consider a wide range of impacts (Sidle and Hornbeck 1991).

Any analysis of the impacts of forest management activities such as logging, prescribed fire, herbicide use or fertilizer application requires the acknowledgment that managed forest ecosystems are affected by multiple disturbances of similar and dissimilar natures that are complex, may interact with each other, occur over expanded and permeable boundaries, and have broad time horizons and inherent time lags (Spaling 1994). These system attributes are inherently cumulative effects and are central to the theory of environmental change and the idea of ecosystems and their response to disturbance (Holling 1973, Barrett et al. 1976, Barrett and Rosenberg 1981). The framework of cumulative environmental change is particularly well suited to analyzing the impacts of herbicide use to water quality at a landscape scale since herbicides disturbance, vegetation removal, fire, planting, and fertilizer application (Neary and Michael 1996, Therivel and Ross 2007, Neary et al. 2011).

Cumulative Effects

Spaling's (1994) paper on cumulative effects assessment approaches the topic from the concept of environmental change theory which is based on ecosystem disturbance concepts in geography (Bennett and Chorley 1978, Holling 1973, Rapport et al. 1985, among others). The main types, characteristics, and examples in forestry are listed in Table 1. Of the cumulative effects types listed in Table 1, space and time crowding are the most common effects on water quality associated with herbicides. Synergistic effects are rare and difficult to quantify. Two herbicides in the same tank mix can affect different target weeds but their effects on water quality are usually not multiplicative. In addition, water quality standards are normally set for individual chemicals and not combinations. Indirect effects on water quality do occur and they can be both negative and positive (Neary and Michael 1996).

Considering the other cumulative effects types, nibbling definitely occurs along stream courses and

Table 1. Cumulative effects types, characteristics, and examples adapted from Spaling (1994).

Type	Characteristics	Examples
Time Crowding	Frequent & repetitive activities in the same time frame	Multiple herbicide applications within a catchment the same day
Space Crowding	Management activities on the same compartment	Harvesting, site preparation, burning, & chemical applications on the same stand
Synergistic	Effects from different activities that multiply the impact	Multiplicative effects of herbicides or fertilizers on vegetation & water quality
Indirect	Secondary effects not directly related to an activity	Nitrogen release into groundwater after harvesting mature stands
Nibbling	Incremental reductions in water quality	Changes in water quality from inputs of pollutants along a stream course
Time Lag	Time delayed effects from land management activities	Delayed movement of fertilizers or herbicide residues into streams
Cross-Boundary	Impacts occurring away from the site of the activity	Chemical drift from fertilized paddocks into forested areas
Trigger/Threshold	Changes in system behavior and characteristics	Global climate change, drought, tropical cyclones
Fragmentation	Change in land use the breaks up continuity of an ecosystem	Urbanization of forest lands or conversions to agriculture

[1]USDA Forest Service, Rocky Mountain Research Station, Flagstaff, AZ

is caused by a number of nonpoint source pollutants, not just herbicides (Sarmah et al. 2004). Sediment and nutrients are the biggest contributors to nibbling effects. Time lag enters into herbicide cumulative effects analyses when residues enter groundwater and their appearance in streams or lakes is substantially delayed. However, the concentrations are usually quite small and do not approach water quality standard limits. Cross boundary effects can occur with aerial applications and often can be the major source of inputs to water despite buffers and computer control of applications. Trigger and threshold effects are not important considerations in herbicide cumulative effects analyses although drought can delay residue movement in soils and excessive rainfall can wash of more herbicide residues into surface waters. In the latter case, herbicide concentrations are likely to be quite low due to dilution effects (Neary et al. 1993). Lastly, fragmentation effects do not enter into herbicide cumulative effects analyses since herbicides by themselves do not fragment landscapes. One aspect of herbicide application in already fragmented landscapes can be higher incidences of cross-boundary effects.

Beanlands et al. (1985) and Orians (1986) stated that the key components of managing cumulative effects are: 1) Determining if cumulative effects are likely, 2) identifying the most appropriate warning signals that cumulative effects are occurring, and 3) attempting to reverse cumulative effects once they have begun to influence ecosystems. In landscapes that have intense and extensive forest management, the big question becomes "Are there water quality effects that occur from multiple disturbances within the same landscape?"

HERBICIDES

Herbicides are commonly used in managed forests to control competing vegetation which is critical to the long-term survival, productivity and economic viability of the timber crop. Herbicide use varies both spatially and temporally within managed forests, and while information exists on the effects of herbicide use on water quality at the site and catchment scale, little is known about the cumulative effects of herbicide use on water quality at the wider landscape scale. This is where a cumulative effects analysis becomes very important for both forest managers and the general public. Since herbicide use in plantation forests is controversial because of its potential to affect water resources, a cumulative effects analysis of many herbicide applications within a large catchment is an important tool for assessing herbicide application impacts on water quality.

Herbicides use in managed forests for control of competing vegetation has been addressed by a number of investigators (Neary et al. 1986, Rolando et al. 2013). The fate and movement of herbicides in forested catchments has been fairly well documented, particularly by research in the USA and Australia (Fagg et al. 1982, Leitch and Flinn 1983, Neary et al. 1993, Skark et al. 2004). Some contradictory results have been produced due to differences in application rates, distribution equipment, and levels of Best Management Practices. For example, the highest concentration of hexazinone reported in streamflow in the literature (2,400 μg L^{-1} or parts per billion) was due to aerial application of herbicide pellets into a perennial stream in Alabama (Miller and Bace 1980). In contrast, a similar aerial application in Tennessee did not produce any detectable levels of hexazinone in streamflow and springflow during a 7-month monitoring period (Neary 1983). Overall, whether applied aerially or through ground application, peak herbicide concentrations were usually detected on the day of application or in storm runoff, particularly in the first few weeks following herbicide application (i.e., Neary et al. 1983, Lavy et al. 1989, Bouchard et al. 1985, Neary et al. 1985, Fiore 1992, Michael and Neary 1993, McBroom et al. 2013, Baillie et al. 2015). Otherwise, herbicide use in forests has generally resulted low concentrations in streamflow (0 to 4 μg L^{-1}) for short durations, often below detection limits (Fagg et al. 1982, Leitch and Flinn 1983, Neary 1983, Neary et al. 1985). All of these studies have been conducted at the level of small stands or catchments. None of these studies have addressed the issue of multiple herbicide applications, or involved any systematic efforts to scale up the results to larger landscapes to assessment the cumulative risks to water quality risk as recommended by Boyle et al. (1997).

NEW ZEALAND STUDY

Recently, a cumulative effects analysis was conducted in the upper Rangitaiki catchment (118,345 ha) in the central North Island of New Zealand, an area dominated by planted forests, to determine the risk to water quality from two herbicides commonly used in New Zealand's planted forests for post-plant weed control, terbuthylazine and hexazinone. Data from a 12.5-ha catchment study within the Rangitaiki Basin, where these two herbicides were aerially applied in two consecutive years, was used to model herbicide concentrations entering the Rangitaiki River for the remaining treated areas in the upper Rangitaiki catchment for the same two spray seasons (Baillie et al. 2015). The spreadsheet model then routed the modelled herbicide residues from their point of entry into the river system to a flow gauge on the Rangitaiki River at the base of upper catchment. Cumulative effects modeling of chemical residue loadings and concentrations of terbuthylazine and hexazinone at this point in the Rangitaiki River catchment, indicated that potential herbicide residues in stream waters would be below analytical detection limits and posed no risk to the aquatic environment or human health and safety. Safety factors for water quality standards, *Daphnia* spp. exposure, *Oncorhynchus mykiss* (rainbow trout) exposure, and human Acceptable Daily Intake levels for both herbicides were very large. The conclusion of this study was that, when taking into account the spatial and temporal variability inherent in the operational landscape level application of terbuthylazine and hexazinone in planted forests in the upper Rangitaiki Basin, no significant risks to water quality, human health, or aquatic species were detected.

SUMMARY

Other cumulative effects analyses need to be done to support or counter the results of the New Zealand study. Despite 15 years of pesticide fate research in the Southeast, there were never any good opportunities to do a cumulative effects analysis (J. L. Michael, pers. comm.). Another cumulative effects study needs to be done that incorporates other water quality parameters such as sediment, anions, cations, and microbiology to get a more complete picture of water quality impacts from herbicide use. Until such a study is installed and completed, one can only conclude from the New Zealand study that there are no adverse cumulative effects impacts from operational herbicide application programs.

REFERENCES

BAILLIE, B, R., and D. G. NEARY. 2015. Water quality in New Zealand's planted forests: A review. *New Zealand Journal of Forestry Science* 45(7). DOI: 10.1186/s40490-015-0040-0

BARRETT G. W., and R. ROSENBERG, eds. 1981. *Stress Effects on Natural Ecosystems*. John Wiley, Chichester. 305 p.

BARRETT G. W., G. M. VAN DYN, and E. P. ODUM. 1976. Stress ecology. *Bioscience* 26:192-194.

BEANLANDS G. E., D. POLICANSKY, W. J. ERCKMANN, M. H. SADAR, G. H. ORIANS, and J. O'RIORDAN, eds. 1985. *Cumulative Environmental Effects: a Binational Perspective*. The Canadian Environmental Assessment Research Council, Ottawa, Canada, and The United States National Research Council, Washington, D.C. 1986. 175 p.

BENNETT, G. W., and R. J. CHORLEY. 1978. *Environmental Systems: Philosophy, Analysis and Control*. Princeton University Press, Princeton, NJ. 624 p.

BOUCHARD, D. C., T. L. LAVY, and E. R. LAWSON. 1985. Mobility and persistence of hexazinone in a forest watershed. *Journal of Environmental Quality* 14:229-233.

BOYLE, J. R., J. E. WARILOA, R. L. BESCHTA, M. REITER, C. C. CHAMBERS, W. P. GIBSON, S. V. GREGORY, J. GRIZZEL, J. C. HAGAR, J. L. LI, W. C. MCCOMB, T. W. PARZYBOK, and G. TAYLOR. 1997. Cumulative effects of forestry practices: An example framework for evaluation from Oregon, U.S.A. *Biomass and Bioenergy* 13:223-245.

CODE OF FEDERAL REGULATIONS. 1971. National Environmental Policy Act of 1969 (CEQ Guidelines, 40, CFR 1508.7, issued 23 April 1971).

FAGG, P. C., J. M. JAMES, D. W. FLINN, and P. MAINEY. 1982. *Residues of Hexazinone and Four of its Metabolites in Stream Water after Aerial Spraying of a* Pinus radiata *Plantation near Yarram, Victoria*. Forest Commission Victoria Report, 9 p.

FIORE, H. 1992. *Water Monitoring Report: 1992 Herbicide Application Projects: Eldorado National Forest*. USDA Forest Service, Eldorado National Forest, 27 p.

HOLLING, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1-23.

LAVY, T. L., J. D. MATTICE, and J. N. KOCHENDERFER. 1989. Hexazinone persistence and mobility of a steep forested watershed. *Journal of Environmental Quality* 18:507-514.

LEITCH, C. J., and D. W. FLINN. 1983. Residues of hexazinone in streamwater after aerial application to an experimental catchment planted with radiata pine. *Australian Forestry* 46:126-131.

MCBROOM, M. W., J. LOUCH, S. R. BEASLEY, M. CHANG, and G. G. ICE. 2013. Runoff of silvicultural herbicides applied using best management practices. *Forest Science* 59(2):197-210.

MILLER, J. H., and A. C. BACE JR. 1980. *Streamwater Contamination after Aerial Application of a Pelletized Herbicide*. USDA Forest Service, Southern Forest Experiment Station, Research Note SO-255. 4 p.

MICHAEL, J. L., and D. G. NEARY. 1993. Herbicide dissipation studies in southern forest ecosystems. *Environmental Toxicology and Chemistry* 12:405-410.

NEARY, D. G. 1983. Monitoring herbicide residues in springflow after an operational application of hexazinone. *Southern Journal of Applied Forestry* 7(4):217-223.

NEARY, D. G., P. B. BUSH, and J. E. DOUGLASS. 1983. Offsite movement of hexazinone in stormflow and baseflow from forest watersheds. *Weed Science* 31:543-551.

NEARY, D. G., P. B. BUSH, and M. A. GRANT. 1986. Water quality of ephemeral forest streams after site preparation with the herbicide hexazinone. *Forest Ecology and Management* 14:23-40.

NEARY, D. G., P. B. BUSH, and J. L. MICHAEL. 1993. Fate of pesticides in southern forests: A review of a decade of progress. *Environmental Toxicology and Chemistry* 12:411-428.

NEARY, D. G., and J. L. MICHAEL. 1996. Herbicides-protecting long-term sustainability and water quality in forest ecosystems. *New Zealand Journal of Forestry Science* 26:241-264.

NEARY, D. G., J. L. MICHAEL, and M. J. M. WELLS. 1985. Fate of hexazinone and picloram after herbicide site preparation in a cut-over northern hardwood forest. Pp 55-72 *in Proceedings of the 1984 Annual Lake States Forest Soils Conference*, L'Anse, MI; September 26-28, 1984.

NEARY, D. G., P. J. SMETHURST, B. BAILLIE, and K. C. PETRONE. 2011. *Water Quality, Biodiversity, and Codes of Practice in Relation to Harvesting Forest Plantations in Streamside Management Zones*. CSIRO Special Report, Canberra, Australia. 99 p.

ORIANS, G. H. 1986. Opening discussions – cumulative effects: Setting the stage. *In* Beanlands, G. E., D. Policansky, W. J. Erckmann, M. H. Sadar, G. H. Orians, and J. O'Riordan, eds., (1985) *Cumulative Environmental Effects: A Binational Perspective*. The Canadian Environmental Assessment Research Council, Ottawa, Canada, and The United States National Research Council, Washington, D.C. 1986. 175 p.

RAPPORT, D. J., H. A. REGIER, and T. C. HUTCHINSON. 1985 Ecosystem behavior under stress. *American Naturalist* 125:617-640.

ROLANDO, C. A., L. G. GARRETT, B. R. BAILLIE, and M. S. WATT. 2013. A survey of herbicide use and a review of environmental fate in New Zealand planted forests. *New Zealand Journal of Forestry Science* 43(1):1-10.

SARMAH, A. K., K. MÜLLER, and R. AHMAD. 2004. Fate and behavior of pesticides in the agroecosystem - a review with a New Zealand perspective. *Australian Journal of Soil Research* 42:125-154.

SIDLE, R. C., and J. W. HORNBECK. 1991. Cumulative effects: a broader approach to water quality research. *Journal of Soil and Water Conservation* 46:268-271.

SKARK, C., N. ZULLEI-SEIBERT, W. UWE, U. GATZEMANN, and C. SCHLETT. 2004. Contribution of non-agricultural pesticides to pesticide load in surface water. *Pest Management Science* 60:525-530.

SPALING, H. 1994. Cumulative effects assessment: Concepts and principles. *Impact Assessment* 12: 231-251.

THERIVEL, R., and B. ROSS. 2007. Cumulative effects assessment – does scale matter. *Environmental Impact Assessment* 27: 365-385.