

THE NED-2 FOREST ECOSYSTEM MANAGEMENT DSS:
THE INTEGRATION OF WILDFIRE RISK AND GIS AGENTS

by

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(Under the Direction of Donald Nute)

ABSTRACT

NED-2 is an intelligent, modular, multi-agent, goal-driven decision support system for forest ecosystem management in cooperative development by the USDA Forest Service and the University of Georgia Artificial Intelligence Center. It offers land managers access to diverse decision support tools through a single user interface. NED-2 currently incorporates the following types of tools: data management; treatment prescriptions; growth and yield models; management models for visual quality, ecology, forest health, timber, water, and wildlife resources; and tabular, hypertext, visualization, and geographic information system (GIS) reporting. It is an open system designed for easy interoperability with third-party models and programs.

This paper addresses the incorporation of two new modules into NED-2. The integration of a wildfire risk management model for the Southern United States is described as well as the integration of ESRI ArcView GIS for graphic reporting and spatial analysis.

INDEX WORDS: Decision support systems, Knowledge based systems, Prolog, Agents, Blackboard architecture, NED, Ecosystem management, Forest management, Wildfire risk, Wildland-urban interface, GIS

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CHAPTER 1

THE NED-2 FOREST ECOSYSTEM MANAGEMENT DSS

NED-2 is an intelligent, modular, multi-agent, goal-driven decision support system (DSS) for forest ecosystem management in cooperative development by the USDA Forest Service and the University of Georgia Artificial Intelligence Center. It offers land managers access to diverse decision support tools through a single user interface. NED-2 currently incorporates the following types of tools: data management; treatment prescriptions; growth and yield models; management models for visual quality, ecology, forest health, timber, water, and wildlife resources; tabular, hypertext, visualization, and geographic information system (GIS) reporting. It is an open system designed for easy interoperability with third-party models and programs.

1.1 A USER'S PERSPECTIVE

The NED-2 Forest Ecosystem DSS is targeted at public and private forest managers overseeing management units that can range from a few dozen to a few thousand acres. A **management unit** (MU) is divided into a number of distinct stands, where each **stand** represents a relatively homogenous and contiguous vegetative cover type such as bottomland hardwoods, loblolly pine plantations, open fields, and agricultural fields. The user must supply site descriptions and vegetative inventories of the stands within the management unit. The user can also select from a list of management goals including visual quality goals like maintaining a continuous canopy, ecological goals like protection of wetlands, forest health goals like fire risk management, timber goals like periodic timber income, water goals like maintaining existing

flow levels, and wildlife goals such as providing habitat for virtually any species of amphibian, reptile, bird, or mammal.

Once the user has supplied information about the stands in and goals for the management unit they can develop any number of custom treatment plans for each stand. **Treatments** are currently focused on silviculture and include actions such as thinning, planting, pruning, and clearcutting. The parameters used to define each treatment are fully user-customizable. A **plan** specifies which treatments are to be applied to which stands in which years. Plans are created in a spreadsheet-like interface where rows correspond to stands and columns correspond to years.

Once a plan is formulated, the user can simulate growth into the future given the specified treatments, and request reports providing vegetative and goal analyses under these projected future conditions. Since the user can create any number of multi-year plans, analysis and reporting are typically focused on a single view of the projected future condition of the management unit. A **view** consists of a set of **snapshots** of the projected condition of the vegetation in each stand for a particular plan and year. Since forest managers are typically interested in the properties of individual stands in a management unit, snapshots of stands are the most significant objects in NED-2.

The user plays a crucial role in the NED-2 decision procedure. NED-2 does not currently recommend treatment regimes to meet the user's goals. The user enters a potential treatment plan; NED-2 simulates the plan, evaluates the plan according to the user's goals, and provides the requested reports. Twery *et al.* (2004) offer a more detailed account of NED-2 from the user's perspective. Glende (2004) offers a detailed account of the simulators and silvicultural treatments currently supported.

A NED-2 user must possess knowledge of typical treatments and their potential effects in achieving their specified goals. They do not need to know how to use the simulators that provide forecasted forest growth given an inventory and treatment specification. They do not need to know how to interpret the simulation results in order to apply them to the scientific models used to analyze their inventories and goals under those forecasted conditions. They do not even need to gather the assorted results together into a consolidated report. The simulators, analysis models, and reporting tools incorporated in NED-2 are totally transparent from the user's perspective. The user only needs to interact with the NED-2 interface by entering inventory data, entering and simulating a treatment plan, and selecting a set of report. Agents within the NED-2 program know how to run simulations, know which analyses will be needed for a given report, know how to perform any analyses, and know how to gather the resultant data into the requested reports.

1.2 A DEVELOPER'S PERSPECTIVE

The NED-2 program uses a number of semi-autonomous agents that communicate and coordinate via a blackboard architecture. The agents and blackboard are implemented in WIN-PROLOG 4.300 (LPA 2002). Microsoft Access databases store all of the inventory and snapshot data for the management unit, data about different plant species, and meta-data about the variables, goals, and reports that are available. The NED-2 interface and code to perform specialized calculations on inventory and simulated data are developed as Dynamic Link Libraries (DLLs) in Microsoft Visual C++.

Each **agent**, or domain control module (DCM), knows how to perform a single specialized task. Tasks include things like interacting with the user, running a simulator, planning the analyses need for reports, creating reports, or analyzing a goal. Adding new third-party components to NED-2 involves both adding the program or model for the component and

developing an agent that knows how to use the component given the supplied inventory data. The agent is responsible for translating between the NED-2 data model and the input and output formats used by the component. **Knowledge bases** hold the models, rules, and other static knowledge needed by an agent to use a third-party component.

Unlike the hierarchical or object-oriented architectures, individual agents in a blackboard architecture need to know little or nothing about how other agents operate. Instead, a **blackboard**, which is accessible to every agent, stores all data of system-wide interest. When an agent sees a **request** for its task on the blackboard, it gathers data from the blackboard, performs its task, and posts the results back to the blackboard as new **facts**. An agent may also post requests for other tasks that need to be performed in order for it to complete its task.

The NED-2 blackboard contains requests, facts, and other Prolog clauses asserted by agents. Additionally, the blackboard offers transparent access to any of the inventory data, plant data, and meta-data stored in the MS Access databases by way of the Prodata Database Interface toolkit for WIN-PROLOG. Requests are stored in a stack on the blackboard. They are accessed by the `request/1` predicate, which has the form

`request(Requests),`

where `Requests` is a list of requests. Agents respond to the first request in the stack, then either add more requests to the list or merely put the remaining requests in the stack back on the blackboard. Other queries to the NED-2 blackboard use the `known/1` predicate, which has the form

`known(Attribute(Object, Value)),`

where the specified `Object` has the `Value` for the specified `Attribute`. Simple Prolog facts

and meta-knowledge, database facts, and even complex derived facts are all accessible to an agent through this same Prolog query.

This overview should provide the reader with a basic understanding of NED-2. Nute *et al.* (2004) provide a more in-depth account of the NED-2 architecture as well as a survey of a number of agents that have been added to NED-2 or are currently in development, including some of the agents herein. Maier (2002) gives a comprehensive account of the implementation of NED-2's blackboard.¹

The following chapters address the incorporation of three new agents into NED-2 and some of the changes to the blackboard architecture that occurred during their implementation. Chapter 2 covers the integration of the wildfire risk analysis agent, which currently uses a combination of scientific models to manage the wildfire risk to buildings and vegetation within management units in the Southern United States.

Chapters 3–5 cover the three wildfire risk models currently used by the wildfire risk analysis agent. Chapter 3 covers the implementation of the Long wildland-urban-interface risk model, Chapter 4 covers the implementation of the Hemel wildland risk model, and Chapter 5 covers the implementation of the Anderson fire behavior fuel models used by both the Long and Hemel risk models. Self-contained quick reference guides to each model are included as appendices.

Chapter 6 covers the integration of two agents that utilize ESRI ArcView GIS by way of custom Visual Basic for Applications (VBA) code. The GIS display agent creates maps, which can graphically display virtually any of NED-2's stand- or MU-level goals and variables. The GIS adjacency agent uses a map of a management unit to determine the adjacency relations

¹ All of the papers cited in this chapter as well as other papers and presentations on NED-2 related topics are available at: <http://www.cs.uga.edu/~potter/dendrite/index.html>

between stands, relieving the NED-2 user from performing this potentially tedious and complex task.

Chapter 7 discusses some new extensions of and constraints on the NED-2 blackboard: the use of derived facts and their integration with the GIS agent and the use of source code checking when accessing the NED-2 databases.

CHAPTER 2

THE WILDFIRE RISK ANALYSIS AGENT

The wildfire risk analysis agent performs the analyses for wildfire-related goals. At present, NED-2 includes a single MU-level goal: *Manage Fire Risk*. To perform the analysis for this goal, the agent currently utilizes a set of models, applicable only to the Southern United States, that cover the wildfire risk to both wildland vegetation and buildings at the wildland-urban-interface (WUI). The agent is designed for easy integration of additional wildfire goals as well as additional wildfire risk models to cover other regions for the currently available goal.

2.1 A FOREST HEALTH RESOURCES MANAGEMENT AGENT

The wildfire risk agent (`fire_analysis.dcm`) handles the analyses for the *Manage Fire Risk* goal. Not only does this represent a new goal in NED-2, it calls for a new category of resource management, namely forest health. This resource category includes management of fire-related goals but could someday be expanded to include goals for disease and pest risk management.

Making new goals available in the user interface is simple: add the goal to the `[Goals]` table in the `NED_Goals.mdb` database by giving it a descriptive name (here, ‘Manage Fire Risk’) and a Prolog program code name (here, ‘fire_risk_mgmt’), assigning it to a resource category (here, ‘Health’), indicating whether it is a stand- or MU-level goal (here, MU-level), and adding a few more entries about how it is displayed in the interface. Adding new resource categories is trivial: assign a goal to the new category.

When the user selects a report on the goal, the reports planning agent will post a request for an agent to analyze the goal. Goal analysis requests are made at the resource-level. The request consists of the resource category, a list of goals for that resource, and a list of snapshots to be analyzed for those goals. This way the report planning agent doesn't need to know much about individual goals – only to which snapshots they should be applied and their resource category.

This is good for the reports planning agent, but requiring a single agent to manage an entire resource category is not always the best approach. Consider again the new forest health resource category. At present, it contains only a single fire-related goal. The wildfire risk agent should be able to handle a request for analysis of this or any other additional fire-related goals. However, if new forest health goals were added for disease or pest prevention, analysis of these goals would likely be inappropriate for an agent specializing in fire-related analyses. A new agent or agents should be created for handling non-fire goals.

In preparation for this possibility, the wildfire risk agent responds to all requests for analysis of forest health goals. The `fire_goals/3` predicate divides the list of goals in the request into fire-related and non-fire-related goals according to whether or not the program code for the goal begins with `'fire_'`. If there are fire-related goals, the `fire_goal_analysis/2` predicate analyzes them and the agent reposts a request for analysis of any remaining non-fire goals. If there are no fire-related goals, the agent does nothing, leaving the current request to be handled by another agent. As NED-2 expands, other agents may benefit from this distributed request handling strategy.

Once the fire-related goals have been extracted from the request, the wildfire risk agent loads the knowledge base (`fire_dfc.kb`) that contains the rules specifying the **desirable future conditions** (DFCs) for the analysis that represent satisfaction of the goals. The agent then

performs one more level of pre-processing in preparation for future expansion of fire-related goals. The `fire_goal_levels/4` predicate further divides the goals into MU- and stand-level goals, since there are slight differences in how these two levels of goal analysis are handled. This scheme would also be more efficient should future expansion result in distributing DFCs among several knowledge bases.

The goals are analyzed by the `fire_goal_mu_analysis/2` and `fire_goal_stand_analysis/1` predicates according to the rules for the appropriate DFCs, and the results are posted as new facts on the blackboard. As yet, there are no stand-level fire-related goals, so handling of stand-level analyses has not been tested.

As with all goal analysis in NED-2, analysis of fire-related goals does not necessarily yield absolute *pass/fail* results. Instead, the NEDCF inference engine uses **confidence factors** (CFs) ranging from 0 to 1 to indicate the degree to which a goal is satisfied. The components of the DFCs are assigned confidence factors according to how well they are fit by the relevant data for the given snapshot or view. In general, the CF is determined by partitioning the data according to thresholds of $\pm 10\%$ of the DFC's target numeric value. The CFs of the components are propagated to assign an overall CF to the goal. This overall CF for the goal can be categorized as *satisfied* (CF = 1.0), *minimally satisfied* (CF = 0.6), *nearly satisfied* or *barely failed* (CF = 0.4), and *failed* (CF = 0.0). This can be especially useful when a management unit has multiple goals with conflicting DFCs. In such cases, it may be preferable, for example, to barely fail all of the goals rather than to definitely pass some and definitely fail others.

2.2 THE *MANAGE FIRE RISK* GOAL

The *Manage Fire Risk* goal has four desirable future conditions (Rauscher 2003). These DFCs combine assessments of the wildfire risk both to the buildings at the wildland-urban-

interface (WUI) and to the wildland vegetation in the stands. **Wildfire risk assessments** for buildings and stands are assumed to be qualitative, with possible values of *Very Low*, *Low*, *Moderate*, *High*, and *Very High*. Satisfaction of the overall *Manage Fire Risk* goal calls for

- 1) no *High* (or greater) WUI risk buildings,
- 2) no *Very High* wildland risk stands,
- 3) less than 10% *High* (or greater) wildland risk by area, and
- 4) no *High* (or greater) wildland risk adjacent stands.

The fourth DFC indicates that overall MU-level goal satisfaction is holistic, not merely determined by an aggregation of building- and stand-level wildfire risk assessments. The first three DFCs involve cumulative properties of individual stands and buildings, but the fourth DFC involves spatial relationships between stands.

2.2.1 IMPLEMENTATION

The top-level `fire_risk_mgmt` rule for the *Manage Fire Risk* goal is implemented in an apparently redundant manner, but, nevertheless, is very efficient. First, the rule calls on the inference engine to analyze each of its four sub-goals outside of the scope of the rule. Then it calls for evaluation of the sub-goals within the scope of the rule. The first set of calls performs all of the analysis of the sub-goals and posts the results to the blackboard. The second set of calls gathers the results of the sub-goal analyses from the blackboard and aggregates them to get the overall CF for this top-level rule. In this case, the overall CF is the minimum sub-goal CF. In general, the inference engine only records CFs for the specific goal that it is called to evaluate; it does not record CFs for individual components of the goal. By taking this seemingly circuitous route, the result for both the overall goal and the sub-goals are placed on the blackboard so that they all can more easily be reported to the user.

The `fire_wui_no_high_risk` rule evaluates the *No High WUI Risk Buildings* sub-goal. First, it gathers a list of all of the buildings in the specified view (set of snapshots). It then gets a WUI fire risk assessment for each building and determines the percent of buildings that pass the DFC, i.e. buildings that do not have a *High* or *Very High* WUI risk. The CF for the sub-goal is determined by requiring that 100% of the buildings pass the DFC. The DFC definitely passes only if no buildings have *High* or *Very High* WUI risk. Otherwise, if no more than 10% of the buildings have *High* or *Very High* WUI risk, the DFC barely fails. Otherwise, the DFC definitely fails.

The `fire_wildland_no_very_high_risk` rule evaluates the *No Very High Wildland Risk Stands* sub-goal. It gets a wildland fire risk assessment for each snapshot in the specified view and determines the percent of the area of stands in the management unit that pass the DFC, i.e. the percent of the area of the management unit that does not have a *Very High* wildland risk. The CF for the sub-goal is determined by requiring that 100% of the management unit pass the DFC. The DFC definitely passes only if no stands have *Very High* wildland risk. Otherwise, if no more than 10% of the area of the management unit has *Very High* wildland risk, the DFC barely fails. Otherwise, the DFC definitely fails.

The `fire_wildland_limit_high_risk` rule evaluates the *Less Than 10% High Wildland Risk By Area* sub-goal. Again, it gets a wildland fire risk assessment for each snapshot in the specified view and determines the percent of the area of stands in the management unit that pass the DFC, i.e. the percent of the area of the management unit that does not have a *High* or *Very High* wildland risk. The CF for the sub-goal is determined by requiring that a minimum of 90% of the management unit pass the DFC. The DFC definitely passes only if no more than 1% of the area of the management unit has *High* or *Very High* wildland risk. Otherwise, if no

more than 10% of the area of the management unit has *High* or *Very High* wildland risk, the DFC minimally passes. Otherwise, if no more than 19% of the area of the management unit has *High* or *Very High* wildland risk, the DFC barely fails. Otherwise, the DFC definitely fails.

The `fire_wildland_no_high_risk_adjacents` rule evaluates the *No High Wildland Risk Adjacent Stands* sub-goal. First, it gathers a list of all of the stands that have a wildland fire risk assessment of *High* or *Very High* for the specified view. Then, for each stand in the list, it gets the list of stands that are adjacent to it and checks to see whether any of those adjacent stands are also in the list of *High* or *Very High* wildland risk stands.² The rule determines the percent of stands in the management unit that pass the DFC, i.e. the percent of stands either that do not have a *High* or *Very High* wildland risk or that do have a *High* or *Very High* wildland risk but are not adjacent to other *High* or *Very High* wildland risk stands. The CF for the sub-goal is determined by requiring that 100% of the management unit pass the DFC. The DFC definitely passes only if there are no adjacent stands that have *High* or *Very High* wildland risk. Otherwise, if no more than 10% of the stands in the management unit are *High* or *Very High* wildland risk adjacent stands, the DFC barely fails. Otherwise, the DFC definitely fails.

2.2.2 COMMENTS

As it stands, the *Manage Fire Risk* goal seems to do a good job of accounting for both WUI and wildland fire risks across the management unit. However, the *No High Wildland Risk Adjacent Stands* sub-goal could perhaps be improved. It does not consider the size of the patches of *High* or greater risk stands. It is no doubt possible that a patch of several adjacent *High* risk stands may exist that is nevertheless smaller in area than other individual *High* risk stands. The intent of the sub-goal seems to be to limit the size of patches of *High* or greater risk stands. The

² All stands that do not have a list of adjacent stands specified are assumed to be adjacent to every other stand.

sub-goal should perhaps be reformulated to find all contiguous patches of *High* or greater risk stands, whether they are individual stands or sets of adjacent stands. The area of the patches could then be compared to an absolute or relative size limit.

Other sub-goals may be desirable as well. For example, the overall goal does not account for road access. Minimally, *High* wildfire risk areas should probably all have road access to allow for a quick response to any fires that do erupt. It may be better yet to have road access to all *High* wildfire risk stands and their adjacent stands.

2.3 WILDFIRE RISK ASSESSMENT

Analysis of the *Manage Fire Risk* goal calls for wildfire risk assessments in both the wildland and wildland-urban-interface domains. An assortment of models may be available to make the risk assessments. All that the *Manage Fire Risk* goal knows about any of the risk models is that they provide assessments that are qualitative and have possible values of *Very Low*, *Low*, *Moderate*, *High*, and *Very High*. In fact, all that is required of the assessments for the *Manage Fire Risk* goal to function properly is that the two worst assessments are *High* and *Very High*. The values of lower assessments are irrelevant.

Following the basic NED-2 modular distributed design principles, the use of wildfire risk assessments in the *Manage Fire Risk* goal is independent of the sources of those assessments. The rules for the goal know nothing about the particular wildfire risk assessment models that are available, know nothing about which models are appropriate to use for the management unit, and know nothing about how the models determine the risk assessments. In order to get the risk assessment for a stand, the rule merely makes a standard query to the blackboard. This is an atypical use of the blackboard, since the risk assessments are not simple facts already asserted as

Prolog clauses and are not available in the databases. Wildfire risk assessments are implemented as complex derived facts. Chapter 7 includes a general account of the use of derived facts.

2.3.1 WILDFIRE RISK ASSESSMENT AS DERIVED FACT BEHAVIORS

Individual wildfire risk assessments are interesting in their own right, apart from their use in the *Manage Fire Risk* goal. The actual fire risk is at the level of buildings and stands, and any treatments to alleviate the risk will occur at this level as well. The wildfire risk of the entire management unit is a secondary concern. This is the motivation for implementing wildfire risk assessments as derived facts. By making the risk assessments available through the blackboard, they are accessible outside of the scope of the *Manage Fire Risk* goal. For example, they can be included in a GIS report.³

The derived facts implementing the wildfire risk assessments (`fire_variables.dut`) act as intelligent behaviors that the blackboard can utilize to respond to queries. The **risk assessment behaviors** are responsible for determining the appropriate risk models for the management unit, loading the corresponding knowledge bases, determining the actual risk assessments, and posting the results as simple facts on the blackboard so that they will be immediately accessible should the risk assessment be needed again. Since, in the course of a NED-2 session, either the data supporting a fire risk assessment may change or the user may switch management units, all of the facts recording risk assessments are removed from the blackboard after each round of reports is produced.⁴ This way, all fire risk assessments will be based on the most recent data.

³ The inclusion of derived facts in GIS displays is covered in Chapter 7.

⁴ All facts with a source of `fire_analysis` are retracted in either `mu_goal_health.pl` or `arcview.dcm`.

2.3.1.1 THE RISK ASSESSMENT INITIALIZATION BEHAVIOR

When a query is made to the blackboard for a wildfire risk assessment, the first behavior to respond is a generic initialization behavior for all wildfire risk assessments. The initialization behavior first checks to see whether or not the knowledge bases for the appropriate risk models have been loaded by looking for the clause

`fire_kbs_loaded(MUName),`

where `MUName` is the name of the management unit loaded in NED-2. If the clause is present, indicating that the knowledge bases are already loaded, the initialization behavior allows the query to be handled by other risk assessment behaviors. Otherwise, the initialization behavior unloads any knowledge bases that may have been previously loaded for a different management unit, determines the appropriate models for the current management unit, loads the corresponding knowledge bases, asserts that the knowledge bases have been loaded, and repeats the query for the wildfire risk assessment. Since knowledge bases are now loaded for the current management unit, when the initialization behavior responds to its own query, it will see that knowledge bases are loaded for the management unit and this time allow the query to be handled by the other risk assessment behaviors.

Selection of the appropriate models and loading of the corresponding knowledge bases are handled by the `fire_get_model/1` predicate, which takes the risk domain as an argument – either `wildland` or `wui`. The currently supported risk models are applicable only to the Southern United States, so the `fire_get_model/1` predicate determines whether or not these models are appropriate by comparing the state where the management unit is located to lists of the states covered by each of the models. If there is no model appropriate for the management unit, the user is asked if they would like to use one of the available models. Other methods of

model selection are possible. Models may eventually be stored as user preferences in the database. The user will need to be queried if more than one model is applicable for the management unit. Once the model is selected, the corresponding knowledge bases are loaded and the name of the model being used is asserted as a Prolog clause on the blackboard.

2.3.1.2 THE BUILDING WUI RISK ASSESSMENT BEHAVIOR

The building WUI risk behavior provides the WUI risk assessment for buildings. It responds to queries in the format:

```
known(
    building_fire_risk(
        [`BUILDING`=Building, `SNAPSHOT`=Snapshot],
        Risk
    )
),
```

where `Building` is the identification number of the building and `Snapshot` is the number of the snapshot of interest. First, the behavior checks that there is not already a fact on the blackboard giving the risk assessment of the building. This prevents unnecessary and unexpected backtracking in the blackboard query. In short, the behavior will not re-calculate an assessment that is already known.

The behavior then calls the NED-2 inference engine on the top-level building WUI risk rule from the previously loaded knowledge base for the applicable WUI risk model. The behavior calls a top-level rule with the format

```
fire_wui_risk([`BUILDING`=Building, `SNAPSHOT`=Snapshot],Risk).
```

Any additional WUI risk models incorporated into NED-2 must take care to use this format for the top-level rule. Again, the behaviors are modular; all they need to know about the WUI risk models is that they all have the same format for the top-level rule.

The resultant fact from the inference engine is retracted from the blackboard and re-asserted in the form

```
fact(
    building_fire_risk(
        ['BUILDING`=Building, `SNAPSHOT`=Snapshot],
        Risk
    ),
    true,
    fire_analysis,
    Time
),
```

where `true` indicates the CF for the fact (1.0), `fire_analysis` records the source of the fact, and `Time` is a timestamp indicating when the fact was asserted. The inference engine must use a different format than that of the fact used on the blackboard, otherwise there will be an infinite loop. A query to the blackboard activates the risk assessment behavior, which calls the inference engine. When the inference engine is called, the first thing that it will do is check whether there is already a corresponding fact on the blackboard. If the inference engine were to use the same format as the blackboard query, when it checks the blackboard it will activate another copy of the risk assessment behavior, which would call the inference engine again, which would check for a fact on the blackboard, and so on, creating an infinite loop.

2.3.1.3 THE STAND WILDLAND RISK ASSESSMENT BEHAVIOR

The stand wildland risk behavior provides wildland risk assessments for snapshots. It responds to queries in the format:

```
known(stand_fire_risk(['SNAPSHOT`=Snapshot],Risk)),
```

where `Snapshot` is the number of the snapshot of interest. The structure of the stand wildland risk behavior is virtually identical to that of the building WUI risk behavior. It verifies that the

wildland risk for the stand has not already been calculated, calls a top-level rule with the format

```
fire_wildland_risk([`SNAPSHOT`=Snapshot],Risk),
```

and re-asserts the result in the form

```
fact(
    stand_fire_risk([`SNAPSHOT`=Snapshot],Risk),
    true,
    fire_analysis,
    Time
)
```

to prevent an infinite loop.

2.3.1.4 THE STAND WUI RISK ASSESSMENT BEHAVIOR

The stand WUI risk behavior provides WUI risk assessments for entire stands rather than individual buildings. The WUI risk of a snapshot is the maximum WUI risk of the buildings in the snapshot. The WUI risk behavior responds to queries in the format:

```
known(stand_wui_risk([`SNAPSHOT`=Snapshot],Risk)).
```

The behavior checks that there is no existing stand WUI risk fact, queries the blackboard for the WUI risks for all of the buildings in the specified snapshot, and asserts the maximum risk to the blackboard in the form

```
fact(
    stand_wui_risk([`SNAPSHOT`=Snapshot],Risk),
    true,
    fire_analysis,
    Time
).
```

2.3.2 WILDFIRE RISK ASSESSMENT MODELS

At present, NED-2 only has a single risk assessment model for each of the wildland and wildland-urban-interface risk domains, the Hemel wildland risk model and the Long WUI risk

model. These models are only applicable to the Southern United States. Additional wildfire risk models may be added in the future to cover other regions. Both models make limited use of the Anderson fire behavior fuel models. The Anderson model could easily be implemented as a fully independent wildland risk assessment model with national applicability. Detailed analyses of the Long, Hemel, and Anderson models appear in Chapters 3, 4, and 5 respectively. These risk assessment models and their interpretations in terms of the NED-2 data model have yet to be fully tested and evaluated. Field testing of the models using NED-2 is expected to begin in late summer of 2004.

2.4 MISSING INVENTORY DATA AND WORST-CASE SCENARIOS

NED-2 has a very rich data model. It is possible that the inventory for a stand will not include all of the data that the data model can account for, especially if the inventory was imported from another program rather than entered directly into NED-2. Land managers focused on timber resources may not have recorded inventory data that does not pertain to the large trees in the overstory, and they may have recorded little or no information about non-forested stands. Many of the variables used for wildfire risk assessments refer to the ground and understory layers of the forest and to static stand characteristics like slope and topographic position, which may not have been recorded. Furthermore, shrub dominated non-forested stands can present some of the highest wildfire risks.

The *Manage Fire Risk* goal and the risk assessment behaviors are equipped to handle missing data and still return useful information to the user. The bulk of the missing data handling, however, must be performed by the individual wildfire risk assessment models. In the event that data is missing, a risk assessment model can return a worst-case scenario assessment by returning a standard risk assessment set off in parentheses. A **worst-case scenario** risk

assessment is the maximum possible risk assessment given the available data. For example, if available data were to indicate possible risk assessments of *Low*, *Moderate*, and *High* then the worst-case scenario assessment would be (*High*). If there is no available data, then the worst-case scenario is (*Very High*).

Missing data does not always cause multiple possible risk assessments requiring a worst-case scenario analysis. Frequently, the calculation of a risk assessment for a particular stand does not utilize every type of data used by the wildfire risk model. It is also possible that a wildfire risk model is over-specified; the model may return multiple assessments that all have the same value. For example, missing data may cause a model to determine a risk assessment to be either *High* or *High*. Regardless of the value of the missing data, the risk assessment is the same.

Several utility predicates are included in `fire_variables.dut` to aid in managing missing variables in the development of knowledge bases for wildfire risk models. The core predicate is `fire_known/2`. This predicate is used in place of `known/1` to query the blackboard. It takes as its arguments the standard Attribute-Object-Value triple used in `known/1` as well as the name of the rule in which the query is made. It makes a standard blackboard query using `known/1`. If the resultant value is 'no data', it asserts a fact in the format

```
fact(
    fire_missing_data(
        [Domain`=Domain, `Model`=Model, `Rule`=Rule|Object],
        Attribute
    ),
    true,
    fire_analysis,
    Time
),
```

where `Domain` is either `wildland` or `wui`, `Model` is the name of the wildfire risk model, `Rule` is the calling rule of the query, `Object` is the full specification of the object of the query, and `Attribute` is the attribute that is missing data.

Three additional utility predicates are used to manage these missing data facts. The predicate `fire_kill_all_missing_data/1` retracts all missing data facts for a specified object. This is useful if a risk assessment fully succeeds despite missing data. The predicate `fire_kill_missing_data/2` retracts all missing data for a specified object and rule. This is useful if a particular rule succeeds despite missing data. The predicate `fire_kill_all_missing_data/2` retracts all missing data for a specified object and for all rules that have names matching the specified rule type. This is useful if a large portion of a risk assessment succeeds despite missing data. For example, all of the rules in the models implemented so far have names in the format *model_rule*, where *model* is the model name and *rule* identifies the particular rule. If a risk assessment uses the Anderson fire behavior fuel models, it can retract all of the missing data facts from the Anderson model by using `anderson` as the rule type. This will match all of the rules in the Anderson model.

Missing data handling and worst-case scenario calculation must be custom tailored to the format of individual risk assessment models. In general, rules are allowed to succeed despite missing data. When an assessment is determined, its value is recorded. However, the presence of missing data facts for the rule causes evaluation to backtrack to look for other rules that may lead to additional assessments. All risk assessments discovered through this backtracking procedure are then used to determine the worst-case scenario.

By returning a worst-case scenario assessment, the land manager can weigh the time and cost of gathering missing inventory data versus the benefits of obtaining a more precise risk

assessment. If the worst-case scenario is (*Low*) or (*Moderate*), the risk assessment will not affect the satisfaction of the *Manage Fire Risk* goal, and it is probably not worth the expense of gathering the missing data.

2.5 THE *MANAGE FIRE RISK* REPORT

NED-2 users typically perform goal analysis by selecting a goal, here *Manage Fire Risk* from the *Health* resource management goals, selecting a goal analysis hypertext report, here the MU-level *Goal Analysis – detail* report, and then generating a particular goal analysis report, here *Management Unit: Goal Report – Manage fire risk*.

The *Manage Fire Risk* goal analysis report includes a number of tables (generated by `mu_fire_risk.pl`), which analyze the goal satisfaction and individual fire risk assessments for the management unit. In particular, the report includes a table showing the overall goal satisfaction along with the satisfaction of the four sub-goals, a management unit summary table that gives a statistical breakdown of the risk assessments, a buildings summary table showing the risk assessments of individual buildings, a stand summary table showing the risk assessments of individual stand, and a missing data table that lists the missing data for each building and stand.

Figures 2-1 – 2-5 depict a sample report for the *Manage Fire Risk* goal applied to a small management unit. The goal satisfaction table, Figure 2-1, indicates that the overall goal has failed due to the failure of the *No High WUI Risk Buildings* sub-goal. The *Less Than 10% High Wildland Risk By Area* sub-goal is shown to be only minimally satisfied. The other sub-goals are fully satisfied.

The management unit summary table, Figure 2-2, is the most complicated table. It gives the model and the statistics for each wildfire risk domain. For the WUI risk, it shows the raw counts and percentages for both the buildings and stands in each risk category. For the wildland risk, it

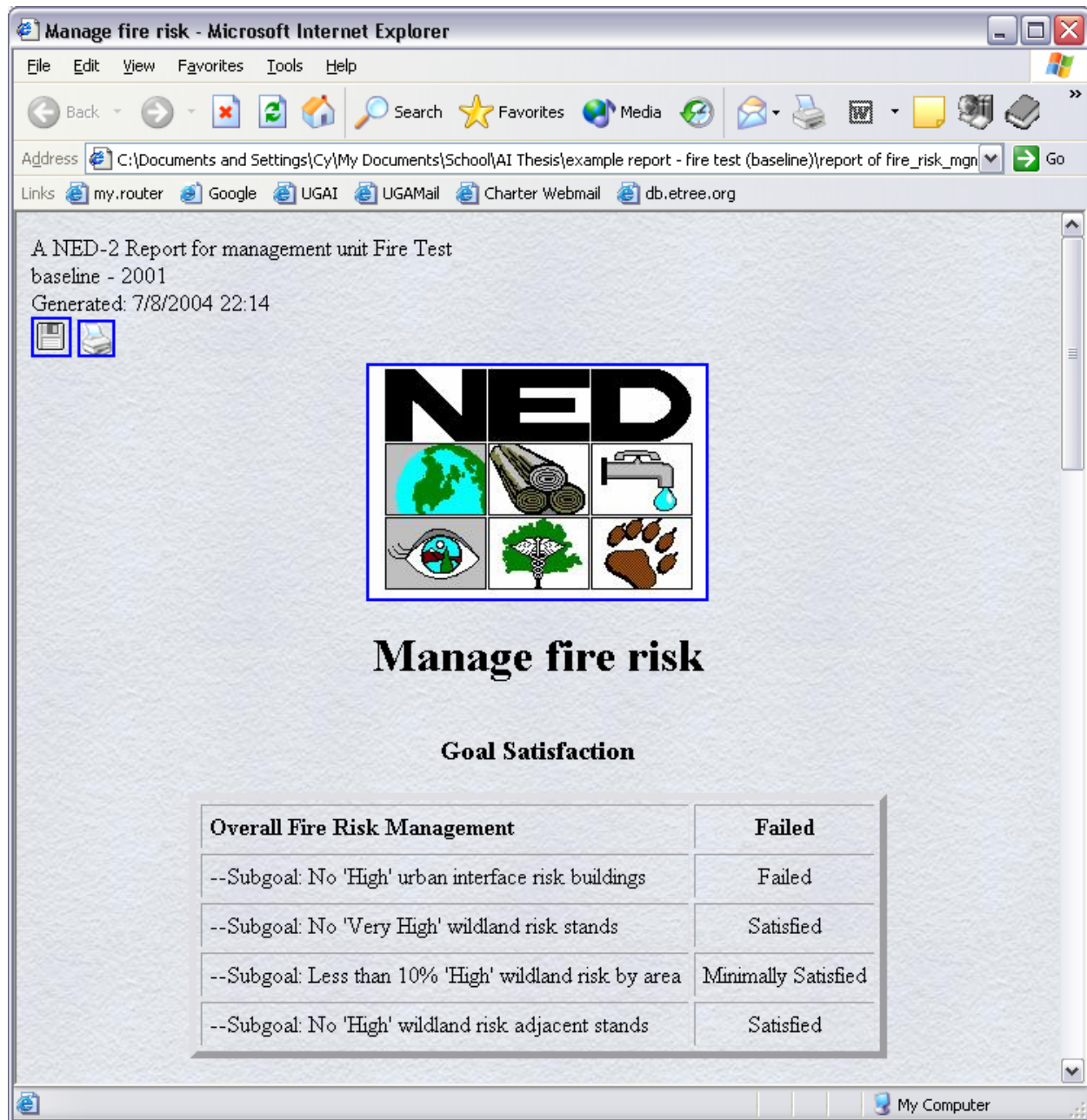


Figure 2-1: The manage fire risk goal report: goal satisfaction table.

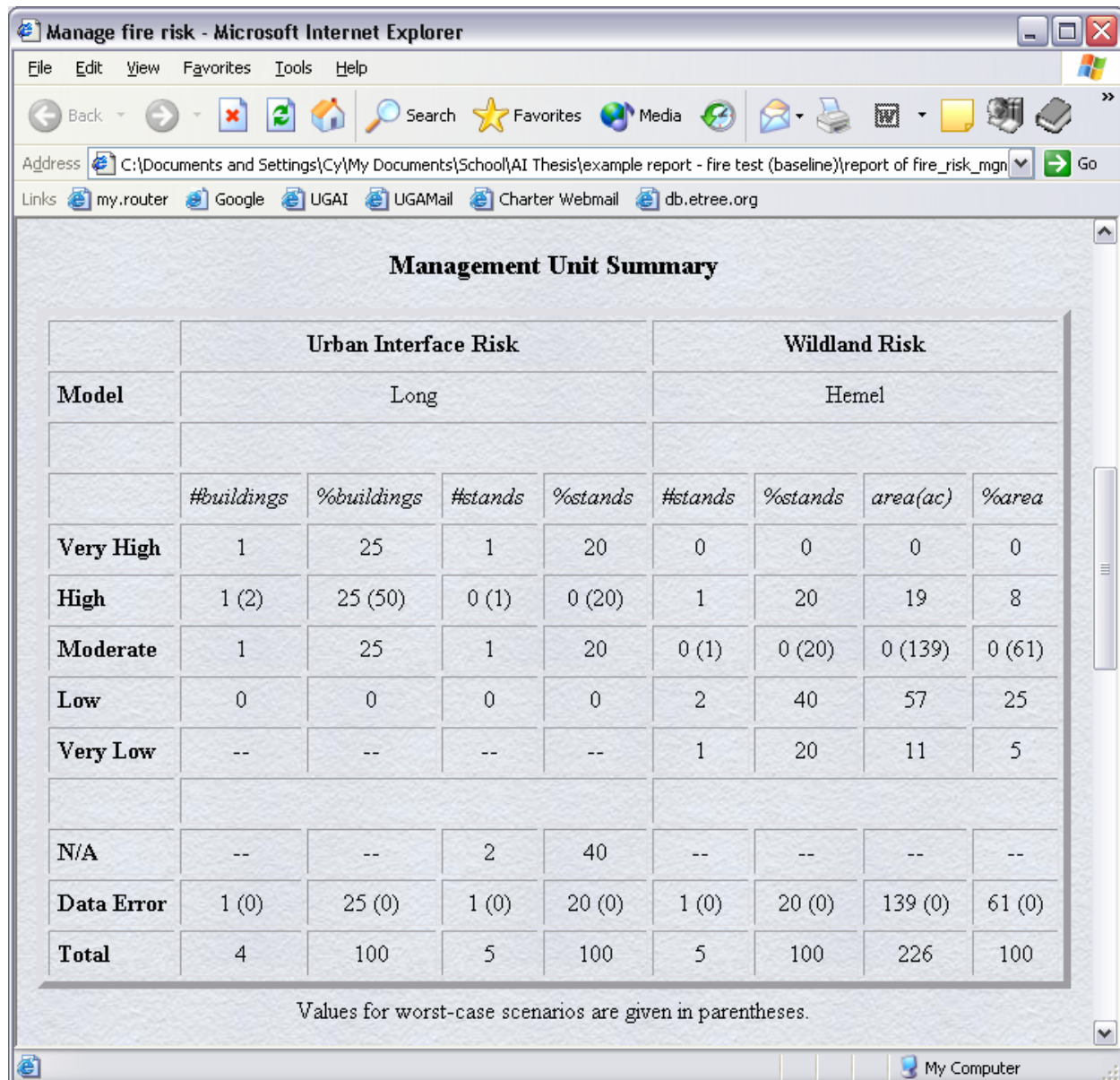


Figure 2-2: The manage fire risk goal report: management unit summary table.

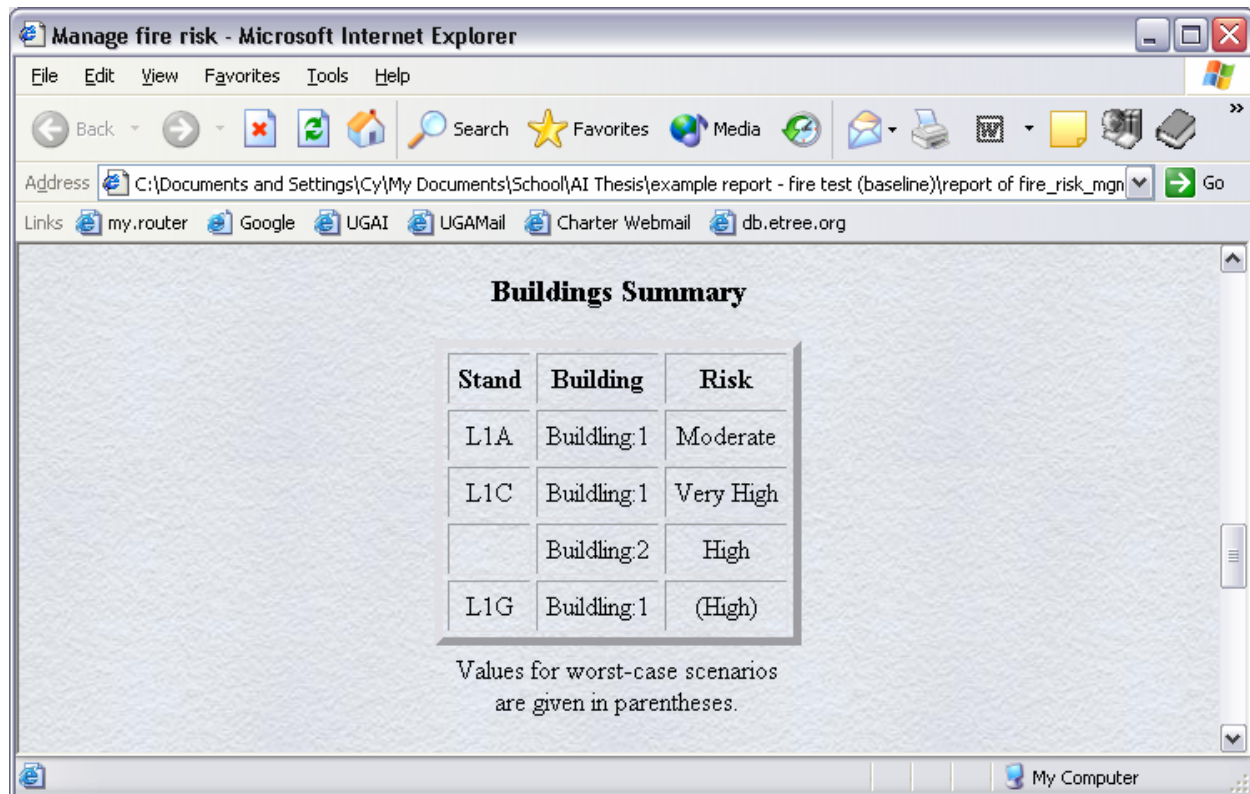


Figure 2-3: The manage fire risk goal report: buildings summary table.

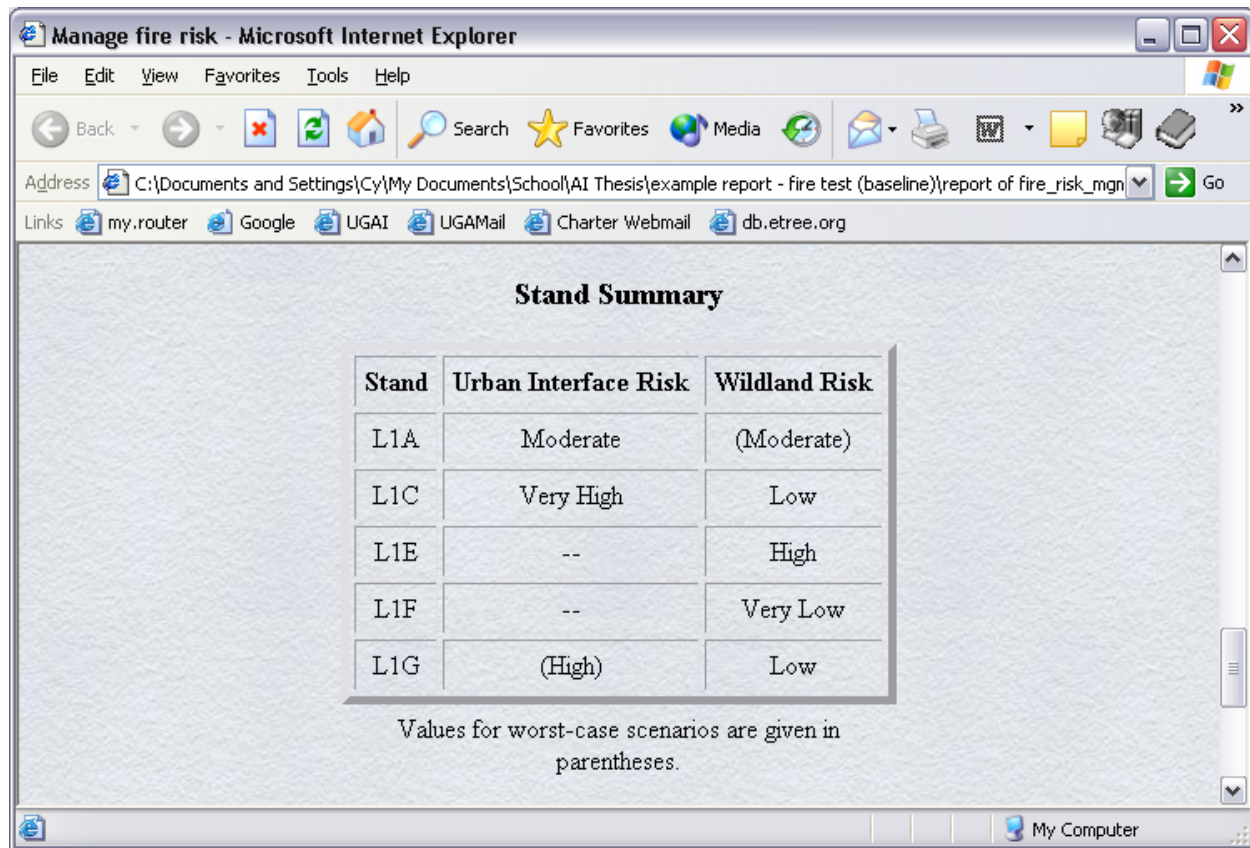


Figure 2-4: The manage fire risk goal report: stand summary table.

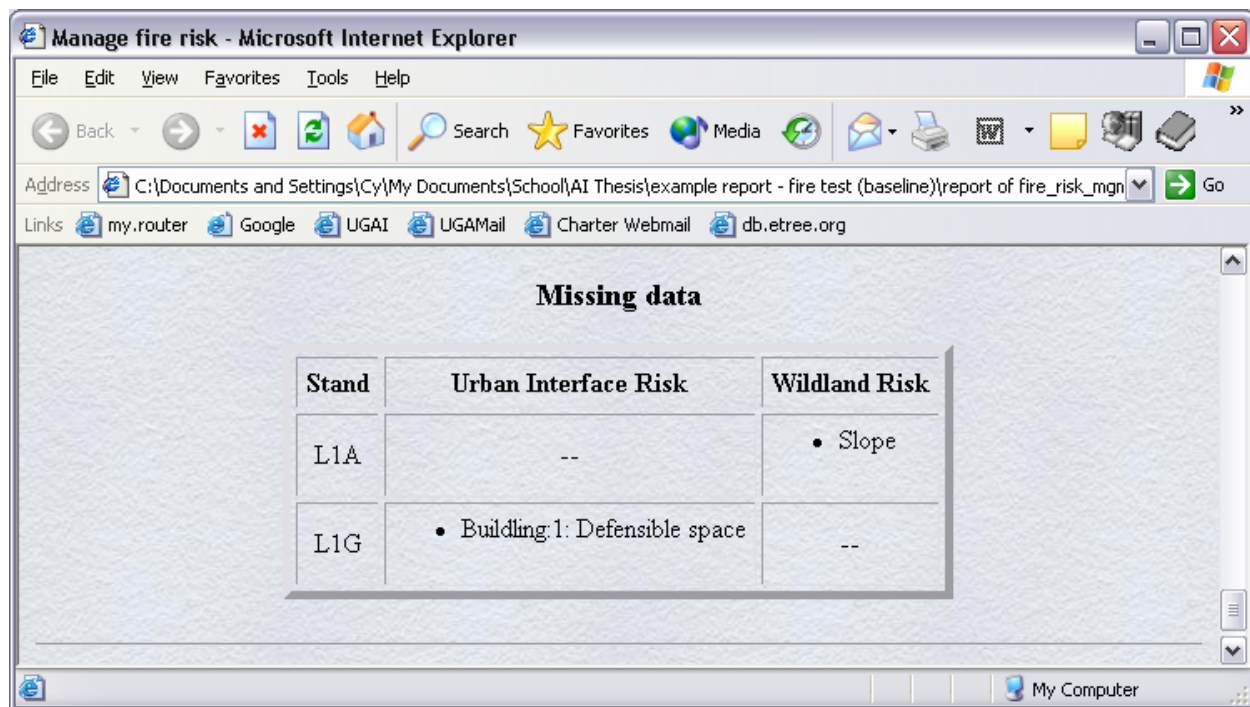


Figure 2-5: The manage fire risk goal report: missing data table.

shows the raw counts and percentages for both the number of stands and total area in each risk category. Worst-case scenarios, where applicable, are given parenthetically. Totals and the number of data errors caused by missing data are given for each column.

The building summary table, Figure 2-3, lists the WUI risk assessment for each building. Here, the assessment for the building *Building:1* in stand *L1G* is a worst-case scenario. The stand summary table, Figure 2-4, lists both the WUI and wildland risk for each stand. The wildland risk for stand *L1A* and the WUI risk for stand *L1G* are worst-case scenarios. The missing data table, Figure 2-5, lists the relevant missing data for stands and buildings according to the risk domain. Stand *L1A* is missing data for the slope. *Building:1* in stand *L1G* is missing data for the defensible space.

2.6 FUTURE DIRECTION

In its present state, the wildfire risk analysis agent is fully operational: the agent is capable of handling the existing *Manage Fire Risk* goal and should be able to handle additional fire-related goals; the *Manage Fire Risk* goal integrates both wildland and wildland-urban-interface risk assessments, although the DFCs for the goal could perhaps be improved and expanded; the risk assessment behaviors are capable of handling any wildfire risk assessment models that conform to the established top-level rule format; risk models are fully implemented for the Southern United States, including worst-case scenario analyses; and the goal report gives the user a fairly complete analysis of fire risks at the MU-level. Nevertheless, a number of aspects of wildfire risk analysis could be improved. The following suggested improvements are roughly ordered from the most essential to the feasible to the most difficult.

2.6.1 HIGH RISK PATCHES TABLE IN THE *MANAGE FIRE RISK* GOAL REPORT

The MU-level goal report for *Manage Fire Risk* gives a complete analysis of all sub-goals except for the ‘No ‘High’ wildland risk adjacent stands’ sub-goal. Wildland risk assessments are given for all stands, but there is no inclusion of adjacency relations. The report should be extended by adding a table that lists all of the stands in each of the individual *High* wildland risk patches.

2.6.2 STAND- AND BUILDING-LEVEL REPORTS FOR THE *MANAGE FIRE RISK* GOAL

The MU-level goal report for *Manage Fire Risk* gives risk assessments for each stand and building, but it does not offer any analyses of these assessments apart from listing any relevant missing data. Individual reports for each stand and building should be available that give detailed accounts of how the risk assessments are determined. Without analysis of the risk assessments, land managers will have no guidance in creating treatment plans to lower wildfire risks.

2.6.3 ADDITIONAL TREATMENTS

At present, all of the treatments available in NED-2 are aimed at silvicultural management. There are no treatments for adding, removing, and modifying buildings, and there are no treatments for managing the shrub- and ground-layer vegetation that plays a large role in wildfire risk assessment. Adding treatments for buildings should be relatively easy. Treatments for shrub- and ground-layer vegetation, such as mowing and prescribed burning, will be more difficult to implement but are still feasible at this stage of development of NED-2.

The greatest impediment to shrub- and ground-layer treatments is the lack of any simulators for vegetative growth at these levels. It may be possible to implement such treatments without the use of a simulator by requiring them to be recurring treatments rather than one-time

treatments. For example, periodic mowing or burning could be assumed to maintain an effectively static and pre-defined state of the shrub- and ground-layers.

The currently implemented silvicultural treatments likely need to be modified as well. It is my understanding that the current treatments for clearcutting, thinning, and pruning do not simulate the production of slash and other down material that result. Slash and down material are important components of wildfire risk assessment. These treatments should be expanded to update the presence of high and low slash if they are not already doing so, and they should update the transect data for the stand, which specifies the amount of down material on the forest floor.

2.6.4 EXTENSION OF THE ANDERSON MODEL FOR WILDFIRE RISK ASSESSMENT

The Anderson fire behavior fuel models are currently used only as components of the Long and Hemel wildfire risk models. These models are applicable only to the Southern United States. The Anderson model, however, could be extended slightly for use as an independent wildland risk assessment model.

The current implementation of the Anderson model, developed by Long (2003) and described in detail in Chapter 5, only includes nine of the thirteen fire behavior fuel models described by Anderson (1982). Excluded are Model 5, covering low, young, green shrubs, Model 10, covering forests with heavy down material, and Models 12 and 13, respectively covering moderate and heavy levels of logging slash. Also excluded is regional information covering types of highly flammable tall shrubs located outside the Southern United States. Mappings from all of the Anderson fire behavior fuel models to qualitative risk assessments are already available. By implementing the missing components outlined above, the Anderson model could be used as a robust wildland risk model with national scope.

2.6.5 ADDITIONAL WILDFIRE RISK ASSESSMENT MODELS

In addition to an Anderson wildland risk model, other wildfire risk assessment models are likely available, especially for the Western United States. Incorporating additional regional or national wildfire risk models into NED-2 would make for robust wildfire risk assessment.

2.6.6 FUZZY ASSESSMENT MODELS

The wildfire risk models currently used by NED-2 utilize qualitative risk assessments. In general, strict numeric thresholds in the rules for a model determine the final risk assessments. For example, if the percent cover of shrubs in a stand is greater than 50% then the risk may be *High*. Otherwise, the risk may be *Moderate*. This threshold may work well for many stands, but may not give the best assessment for stands with percent cover very near 50%, which should be considered to have both *Moderate* and *High* risk to some degree. Modifying the risk models to use fuzzy logic to capture the degree of membership in the various risk categories could do a better job of classifying borderline cases.

2.6.7 UNDERSTORY SIMULATION

A final, and perhaps most crucial, missing component in wildfire risk analysis is understory simulation of ground- and shrub-level vegetation. An understory simulator is necessary for reliable wildfire risk forecasting in long-term management planning. It is also a crucial component for long-term wildlife resource management, since the understory provides the primary habitat for many animal species.

Development of an understory simulator should be a high priority for future versions of NED. At present, there is no understory simulation in NED-2. The same data for the ground- and shrub-layers is merely copied from the inventory into the snapshots for future years. This may

provide reasonable results for older, established stands that are not subject to silvicultural treatments. The inventory of the understory is likely to represent a steady-state of the ground- and shrub-layers. This steady-state assumption will not be applicable for young or logged stands and could result in under-estimation of future wildfire risks.

CHAPTER 3

THE LONG WILDLAND-URBAN INTERFACE RISK MODEL

Alan Long (2003) offers a wildland-urban-interface (WUI) risk model to determine the wildfire risk to buildings in the Southern United States.⁵ The risk assessment is based on the vegetation surrounding the building and the characteristics of the building itself. These two main components of the WUI fire risk assessment are further divided into sub-components, each of which is assigned a point value. The points of the sub-components are combined to give the overall wildfire risk to the building. Higher point totals indicate higher fire risk to the building. A quick reference guide to the Long WUI risk model is included as Appendix A.

3.1 IMPLEMENTATION

The implementation of the Long WUI risk model (`fire_wui_long.kb`) assigns individual buildings qualitative risk assessments in the range *Low*, *Moderate*, *High*, and *Very High*. Risk assessments are obtained by calling the NEDCF inference engine for the rule

```
fire_wui_risk([`BUILDING`=Building, `SNAPSHOT`=Snapshot],Risk),
```

where `Building` is the identification number of the building, `Snapshot` is the snapshot containing the building, and `Risk` is the assessment returned. The implementation has robust missing data handling capabilities, returning a worst-case scenario assessment when required inventory data is not available.

⁵ The model is applicable in the following states: Alabama, Arkansas, North Carolina, South Carolina, Florida, Georgia, Kentucky, Louisiana, Mississippi, Tennessee, Texas, and Virginia.

The WUI risk assessment for a building is determined by assigning points to a number of risk factors. **Risk factor points** are used to score assorted fire risks to a building imposed by both nearby vegetation and the flammability of the building's structural components. The *Total Risk* points for a building are a combination of the *Hazardous Fuels* risk factor points and the *Structural Hazard* risk factor points:

$$\text{Total Risk} = \text{Hazardous Fuels} + \text{Structural Hazard}.$$

The mapping from *Total Risk* points to the WUI risk assessment is given in Table 3-1.

Table 3-1: The mapping from total risk factor points to WUI risk assessments.

Total Risk Points	WUI Fire Risk.
> 13	Very High
9-13	High
5-8	Moderate
< 5	Low

The *Hazardous Fuels* risk factor points represent the fire risk from the vegetation surrounding the building. They are determined by a combination of the *Adjacent Area Hazard* risk factor points and the *Defensible Space* risk factor points:

$$\text{Hazardous Fuels} = \text{Adjacent Area Hazard} \times \text{Defensible Space}.$$

The *Structural Hazard* risk factor points represent the risk inherent in the structural components of the building itself. They are determined by a combination of the *Firebrand Ignition* risk factor points, the *Indirect Ignition* risk factor points, and the *Direct Ignition* risk factor points:

$$\text{Structural Hazard} = \text{Firebrand Ignition} + \text{Indirect Ignition} + \text{Direct Ignition}.$$

If a building possesses multiple risk factors for one of these structural components, only the

points associated with the highest risk factor should be used. Point allocations for each of the basic risk factor point components are covered below.

3.1.1 ADJACENT AREA HAZARD

The type of vegetation surrounding the building determines the *Adjacent Area Hazard* risk factor. The Anderson fire behavior fuel models are used to determine the risk imposed by the surrounding vegetation. A full account of the Anderson model is given in Chapter 5. The risk factor points corresponding to the wildland risk assessment of the surrounding area are shown in Table 3-2.

Table 3-2: Adjacent area hazard risk factor points for wildland risk assessments.

Wildland Risk	Adjacent Area Hazard Pts.
Very High	5
High	4
Moderate	2
Low	1
Very Low	0

There is an ambiguity in deciding what constitutes the relevant adjacent area. Long (2003, p. 4) considers the adjacent area to be all wildland areas within 200 feet of the building. In some cases, the relevant adjacent area is entirely included in the stand containing the building. In other cases, the relevant adjacent area is represented by other stands in the management unit. Typically, the relevant adjacent area will include other stands only if the building is in a stand with an urban or agricultural land cover type. If the stand containing the building has an urban or agricultural land cover type, then the maximum Anderson wildland risk assessment of all

adjacent stands is used to determine the risk factor. Otherwise, the Anderson wildland risk of the stand containing the building is used. The urban and agricultural land cover types available in NED-2 are listed in Table 3-3.

Table 3-3: Urban and agricultural land cover types in NED-2.

Urban and Agricultural Land Cover Types
'Urban and built-up land'
'Residential'
'Commercial, Services & Institutional'
'Industrial'
'Transportation, Communication and Utilities'
'Industrial/Commercial complexes'
'Mixed urban or built-up land'
'Other urban or built-up land'
'Agricultural land'
'Cropland and pasture'
'Orchards, bush fruits, vineyards, nurseries & ornamental horticulture'
'Confined feeding operations'
'Other agricultural land'

3.1.2 DEFENSIBLE SPACE

The defensible space of a building is the space between the building and any adjacent wildland areas that has been maintained or partially cleared of flammable materials. This space allows firefighting crews the space to operate and acts as a natural firebreak protecting the building. The minimum distance between the building and adjacent wildland areas determines the *Defensible Space* risk factor. The risk factor points associated with varying amounts of defensible space are given in Table 3-4.

Table 3-4: Defensible space risk factor points.

Defensible Space	Defensible Space Pts.
< 30 ft.	4
30-60 ft.	2
60-100	1.5
> 100	1

3.1.3 FIREBRAND IGNITION FACTORS

Firebrands are floating embers from a fire, which can ignite some structural components of a building “even when the fire is hundreds of feet away” (Long 2003, p. 6). The components most susceptible to firebrands are wood shingles or shakes (Class C or not rated). Other structural components and aspects that make a building susceptible to firebrands are wood decks, open soffits, and open foundations. The risk factor points associated with *Firebrand Ignition* are given in Table 3-5.

Table 3-5: Firebrand ignition risk factor points.

Firebrand Ignition Factors	Firebrand Ignition Pts.
Wood shingles or shakes	5
Wood deck	3
Open soffits	3
Open foundation	3
None of the above	0

3.1.4 INDIRECT IGNITION FACTORS

The area around a building can produce a number of factors that increase the likelihood that the building will catch fire. These *Indirect Ignition* factors may increase the intensity of a wildland fire in the immediate vicinity of the building or may be other flammable objects near the building. Indirect ignition sources include site slopes over 30%, wood fencing connected to the building, adjacent buildings within 50 feet, and firewood stacked near the building. The risk points associated with these *Indirect Ignition* factors are given in Table 3-6.

Table 3-6: Indirect ignition risk factor points.

Indirect Ignition Factors	Indirect Ignition Pts.
Slope > 30%	2
Wood fence	2
Adjacent building < 50 feet	1
Stacked firewood	1
None of the above	0

3.1.5 DIRECT IGNITION FACTORS

Many of a building's structural components are resistant to firebrands but may be ignited by radiant heat from or direct contact with nearby fire. *Direct Ignition* factors should only be included in a building's overall risk if the building has less than 100 feet of defensible space. Structural components susceptible to radiant heat or direct flame contact include wood siding, vinyl siding or soffits, and single-paned non-tempered glass windows. The risk points associated with these *Direct Ignition* factors are given in Table 3-7.

Table 3-7: Direct ignition risk factor points.

Direct Ignition Factors*	Direct Ignition Pts.
Wood siding	3
Vinyl siding or soffits	2
Single paned, non-tempered windows	2
None of the above	0

**applicable only if defensible space is less than 100 feet.*

3.2 COMMENTS

The weakest part of the implementation of the Long WUI risk model is the calculation of the *Adjacent Area Hazard*. Long (2003, p. 4) defines the adjacent area as all wildland areas within 200 feet of the building. There is currently no way to determine precisely which stands are included in the adjacent area. Instead, a heuristic method is used. If the stand containing the building has an urban or agricultural land cover type, include all adjacent stands in the building's adjacent area. Otherwise, include only the stand including the building. This method attempts to account for the fact that urban stands are often relatively small and that buildings are often located near the edge of a stand.

This method will likely overestimate the *Adjacent Area Hazard* for buildings in urban and agricultural stands by including too many stands in the adjacent area. This is especially true if land managers have not uniquely identified these urban and agricultural stands, which is often the case. Non-unique identification of these stands interferes with the determination of adjacent stands and can lead to the inclusion of stands from distant parts of the management unit in the adjacent area of a building. More importantly, this method may underestimate the *Adjacent Area*

Hazard for buildings in wildland stands if the building is located near the edge of the stand and other nearby stands pose a higher wildfire threat.

The best way to remedy this weakness in the calculation of the *Adjacent Area Hazard* would be to add an additional variable to the NED-2 data model for buildings that lists all stands within 200 feet of the building. This should be a relatively simple item to inventory and would allow for precise determination of the *Adjacent Area Hazard*. Furthermore, it would allow land managers to continue to assign non-unique identifications to stands without affecting the quality of WUI risk assessments.

The only other weakness in this implementation of the Long WUI risk model, also related to the calculation of the *Adjacent Area Hazard*, is the hard-coded usage of Anderson wildland risk assessments. If only to increase consistency, the wildland risk model used in the wildland-urban-interface domain should be the same risk model used in the wildland domain.

CHAPTER 4

THE HEMEL WILDLAND RISK MODEL

Brian Hemel (2004) offers a wildland risk model to determine the wildfire risk to forested stands in the Southeastern United States.⁶ The risk assessment is based on eight variables characterizing the vegetation and topography of the stand. The wildfire risk assessment is obtained by matching the values of these variables to entries in a large lookup table (see Table B-1). The Hemel model does not cover non-forested stands. In order to make the model complete, the Hemel wildland risk model implemented in NED-2 uses Anderson risk assessments, described in Chapter 5, for non-forested stands.⁷ A quick reference guide to the Hemel wildland risk model is included as Appendix B.

4.1 IMPLEMENTATION

The implementation of the Hemel wildland risk model (`fire_wildland_hemel.kb` and `fire_wildland_hemel_rules.kb`) assigns individual stands qualitative risk assessments in the range *Very Low*, *Low*, *Moderate*, *High*, and *Very High*. Risk assessments are obtained by calling the NEDCF inference engine for the rule

```
fire_wildland_risk(['SNAPSHOT'=Snapshot],Risk),
```

where `Snapshot` is the snapshot of the stand and `Risk` is the assessment returned. The

⁶ The model is applicable in the following states: Alabama, Arkansas, North Carolina, South Carolina, Florida, Georgia, Kentucky, Louisiana, Mississippi, Tennessee, Virginia, and West Virginia

⁷ If it is necessary to distinguish between the risk model offered by Hemel (2004) and the expanded risk model implemented in NED-2, Hemel's model will be referred to as 'the Hemel forest risk model' and the expanded NED-2 implementation will be referred to as 'the Hemel wildland risk model'.

implementation has robust missing data handling capabilities, returning a worst-case scenario assessment when required inventory data is not available.

The Hemel forest risk model determines the wildland risk assessment of forested stands from the values of eight variables characterizing the stand's vegetation and topography: forest *Composition* and *Canopy Structure*; topographic *Landform*, *Aspect*, and *Slope*; and the presence of *Fine Debris*, *Medium Debris*, and *Ladder Fuels*.⁸ It also includes some special case rules that provide superseding risk assessments. The interpretation of the special cases and the calculation of each of the vegetative and topographic variables using the NED-2 data model are covered below. For non-forested stands, the Hemel wildland risk model uses Anderson risk assessments, covered in Chapter 5. If, for some reason, it is not clear whether or not a stand is forested, the higher of the Hemel forest risk assessment and the Anderson wildland risk assessment is used.

4.1.1 SPECIAL CASES

An abundance of rhododendron (*Rhododendron*) or mountain laurel (*Kalmia latifolia*) increases the fire risk in a stand. The chemical composition of the leaves of these species is highly flammable (Hemel 2004, p. 4–5). If either of these species is present in the ground or understory observations in the inventory of a stand, then the wildland risk assessment for the stand is *Very High*. Hemel also sites stands that have been damaged by southern pine beetles (*Dendroctonus frontalis*) as having *Very High* wildfire risk (2004, p. 4), but there is currently no way to adequately implement this special case in NED-2.

⁸ The rules used to determine the Hemel forest risk from the eight model variables are stored in a separate knowledge base (`fire_wildland_hemel_rules.kb`) from the rules used to calculate the model variables from NED-2 inventory data (`fire_wildland_hemel.kb`). Hemel's risk assessment rules are recorded in a spreadsheet. Code to create Prolog rules from the spreadsheet (`fire_wildland_hemel_csv2rules.pl`) is stored in the 'DEVELOPMENT TOOLS' folder on UGA's *fsproj* server.

4.1.2 FOREST COMPOSITION

The *Composition* of a forest is a major factor in determining wildfire risks. In general, coniferous forests have a much greater fire risk than hardwood forests. NED-2 classifies forests into numerous forest types and into several land cover types. The land cover type is used to determine the *Composition* of a forested stand. The forested land cover types available in NED-2 are listed in Table 4-1.

Table 4-1: Forested land cover types in NED-2.

Forested Land Cover Types
'Forest'
'Broadleaf forest'
'Coniferous forest',
'Mixed Coniferous/Broadleaf forest'
'Forested wetland'

NED-2 can calculate the land cover type of forests from the tree species in a snapshot, so the 'Forest' type should not actually occur in the data used for wildfire risk analysis. The *Composition* of a 'Broadleaf forest' or 'Forested wetland' is *Hardwood*. The *Composition* of a 'Coniferous forest' is *Pine*. For a 'Mixed Coniferous/Broadleaf forest', it is useful to know whether there are more coniferous or hardwood trees. The basal areas of the conifers and hardwoods in a stand are compared to determine which is more prevalent. If the percent basal area of conifers is greater than or equal to that of hardwoods, then the *Composition* is *Mixed, More Pine*. Otherwise, the *Composition* is *Mixed, More Hdw*. All non-forested land cover types are given a *Composition* of *Non-Forest*.

The Anderson wildland risk model and, derivatively, the Long WUI risk model, require the classification of forests as either coniferous or hardwood; they do not account for mixed forests. Therefore, the *Composition* rules are stored as a separate knowledge base (fire_forest_comp.kb) so that all of the models can use the same *Composition* assessments.

4.1.3 LANDFORM

The topographic *Landform* of a stand affects its wildfire risk. In general, the higher the topographic position, the higher the fire risk. The conversion from the topographic position used by NED-2 and the *Landform* is given in Table 4-2.

Table 4-2: Topographic positions and landforms.

Topographic position	Landform
'bottomland, flatland'	Valley Floor
'upland plateau'	Valley Floor
'upland bottom'	Valley Floor
'lower slope'	Lower Slope
'bench'	Lower Slope
'midslope'	Upper Slope
'upper slope or shoulder'	Upper Slope
'ridge top'	Ridge Top

4.1.4 ASPECT

The aspect of a stand determines the amount of direct sunlight that a slope receives. South and west facing aspects will be affected most by direct sunlight and daytime heating, which tends

to dry out vegetation, making it more susceptible to fire. North and east facing aspects are shadier and retain more moisture. If the stands aspect is between 135° and 315°, inclusive, then the *Aspect* is *South*. Otherwise, the *Aspect* is *North*.

4.1.5 SLOPE

Steep slopes will cause fires to spread faster due to upslope convective heating and also tend to increase wind, which dries fuels and feeds and carries fires (Hemel 2004, p. 2–3). If the stand's slope is greater than or equal to 30%, then the *Slope* is '30+'. Otherwise, the *Slope* is '<30'.

4.1.6 CANOPY STRUCTURE

Canopy structure determines the amount of direct sunlight that reaches the forest floor and also affects oxygen flows that feed fires. Young stands tend to have an open canopy; intermediate aged stands tend to have a tightly closed canopy; mature stands tend to develop gaps in an otherwise closed canopy.

Stands with a predominantly hardwood *Composition* and an age of less than 5 years have a *Canopy Structure* that is *Un-Closed*. Stands with a predominantly coniferous *Composition* and an age of less than 10 years also have a *Canopy Structure* that is *Un-Closed*. Stands with a canopy closure of 50% or more that are mature, 60 years or more for stands with a predominantly coniferous *Composition* and 120 years or more for stands with a predominantly hardwood *Composition*, have a *Canopy Structure* that is *Closed With Gaps*. Otherwise, if the canopy closure is of 50% or more, the *Canopy Structure* is *Closed*. Otherwise, the *Canopy Structure* is *Un-Closed*.

4.1.7 FINE DEBRIS

Most wildfires start in and are spread by surface litters like leaves and pine needles. This fine debris on the forest floor is the most likely to ignite. If the litter depth in a stand is 3 or more inches, the *Fine Debris* is '3+'. Otherwise, *Fine Debris* is '<3'.

4.1.8 MEDIUM DEBRIS

Medium-sized debris on the forest floor, like fallen branches, allows fires to grow in intensity and burn longer. Transects record the amount of dead down material on the forest floor. If transect data for a stand records any dead down material with a diameter of 1 to 3 inches, then *Medium Debris* is *Present*. Otherwise, *Medium Debris* is *Not present*.

4.1.9 LADDER FUELS

Ladder fuels allow surface fires to spread into the forest canopy. For ladder fuels to be present, there must be a significant fuel load at the ground, shrub, and midstory levels. If the ground cover in a stand is 30% or more, then ground-level fuels are present. If either the shrub cover is 30% or more or low logging slash covers 30% or more of the stand, then shrub-level fuels are present. If either coniferous midstory trees or high logging slash cover at least 30% of the stand, then midstory-level fuels are present. If fuels are present at each of the ground, shrub, and midstory levels, then *Ladder Fuels* are *Present*. Otherwise, *Ladder Fuels* are *Not present*.

4.2 COMMENTS

Some of the specifications for the variables in the Hemel forest risk model may require fine-tuning. The calculation for the presence of *Ladder Fuels* looks for either shrub cover or low slash and either coniferous midstory or high slash. It may be preferable to combine the percent cover of both elements at each height level. The implementation of the Anderson risk model

(Chapter 5) accounts for ladder fuels in a different manner, which may be applicable in the Hemel forest risk model as well. There, for stands with significant shrub-level fuels, the calculation checks for a safe distance of 15 feet between the average shrub height and the bottom of the canopy. If there is not a safe distance between the shrubs and the canopy or if significant midstory level fuels are present, then ladder fuels are present.

The presence of *Medium Debris* is calculated from transect data. The current NED-2 field procedure for transects calls for recording only dead down logs with a diameter of 3 or more inches. *Medium Debris* is defined as dead down branches between 1 and 3 inches in diameter. The field procedure needs to be modified in some way to account for these branches. Furthermore, there is no rule component specifying the amount of *Medium Debris* that is required to count as *Present*; a single branch in a 100 foot transect would count as the presence of *Medium Debris*. The most economic solution seems to be to record only counts of branches along a transect and to set a threshold value for branches per transect foot to determine whether or not *Medium Debris* is *Present*.

CHAPTER 5

THE ANDERSON FIRE BEHAVIOR FUEL MODELS

Anderson (1982) provides descriptions of thirteen fuel models used to classify fire behavior in wildland areas. The fuel models are applicable nationally. They are divided into a grass group containing fuel models 1–3, a shrub group containing fuel models 4–7, a timber group containing fuel models 8–10, and a slash group containing fuel models 11–13. Long (2003) provides the basis of the procedural method implemented in NED-2 to determine the Anderson fuel model of a stand and the corresponding wildfire risk assessments. A quick reference guide to the Anderson wildland risk model is included as Appendix C.

5.1 IMPLEMENTATION

The implementation of the Anderson fire behavior fuel models (`fire_anderson.kb`) can return either the fuel model itself or the corresponding wildfire risk. A stand's fuel model is obtained by calling the NEDCF inference engine for the rule

```
fire_anderson(['`SNAPSHOT`=Snapshot'],FuelModel),
```

where `Snapshot` is the snapshot of the stand and the value returned by `FuelModel` is either a definite single fuel model or a list of all possible fuel models. A stand's risk assessment is obtained by calling the NEDCF inference engine on the rule

```
fire_anderson_risk(['`SNAPSHOT`=Snapshot'],Risk),
```

where `Snapshot` is the snapshot of the stand and `Risk` is the assessment returned. Risk assessments are qualitative, providing risks in the range *Very Low*, *Low*, *Moderate*, *High*, and

Very High. The implementation has robust missing data handling capabilities. When required inventory data is not available, the model returns either a list of all possible fuel models or a worst-case scenario risk assessment.

The Anderson risk model implemented in NED-2 expands on Long's procedure to include additional fuel sub-models and a degenerate non-wildland fuel model. These additions yield a complete risk model that can assign a risk assessment to any stand. The additions also yield a model with soft transitions between risk assessments; no single threshold within this expanded procedure will lead to divisions between risk assessments that are not contiguous. For example, no single threshold would divide assessments between *Low* and *High* wildfire risk. Instead, a sub-model would be included to produce an intermediate case with *Moderate* risk. The procedure to obtain the Anderson fuel model for a stand is described below. Conversion from fuel models to risk assessments is covered in Section 5.2.

5.1.1 COARSE CATEGORIZATION

The first step in obtaining the fuel model for a stand involves a coarse classification of the stand's vegetation. Recently logged stands are all currently assigned to the same fuel model. If the total low slash and high slash is 50% or more, then use *Fuel Model 11*. *Fuel Model 12* and *Fuel Model 13* cover greater levels of logging slash not typically found in the Southern United States.

For forested stands with canopy closure of 50% or more, either use the *Hardwood Forest Model* rules if the stand has a predominantly hardwood *Composition* or use the *Coniferous Forest Model* rules if the stand has a predominantly coniferous *Composition*. Otherwise, for forested stands with a relatively open canopy and shrub cover of at least 30%, use the *Shrub and*

Brush Model rules. For forested stands with open canopies and little shrub cover, use the *Herbaceous, Agricultural, Urban, Water, or Barren Model* rules.

If the stand's land cover type indicates that shrub and brush predominate, use the *Shrub and Brush Model* rules. The shrub and brush land cover types available in NED-2 are listed in Table 5-1. All other stands are assigned fuel models by the *Herbaceous, Agricultural, Urban, Water, or Barren Model* rules.

Table 5-1: Shrub and brush land cover types in NED-2.

Shrub and Brush Land Cover Types
'Brush or transitional between open and forested'
'primarily shrub/brush (75% or more cover)'
'mixed herbaceous and shrub/brush'
'Shrub and brush'

5.1.2 HARDWOOD FOREST MODELS

Hardwood forests with relatively closed canopies can fall into either the timber or shrub group of fuel models depending on the amount of surface fuels. If the shrub layer is extensive, covering 50% or more of the stand, use *Fuel Model 6* for shrubs and dense immature hardwoods. Otherwise, if either the shrub cover is moderate (30% or more) or the canopy is very low (the height to the bottom of the canopy is less than 15 feet), then use *Fuel Model sub-6* for moderate density immature hardwoods. If the stand is a wetland, use *Fuel Model 8* for seasonally flooded swamps. Otherwise, use *Fuel Model 9* for mature forests.

5.1.3 CONIFEROUS FOREST MODELS

Coniferous forests with relatively closed canopies can fall into either the timber or shrub group of fuel models depending on the amount of surface fuels. Large amounts of surface fuels in coniferous forests can drastically increase wildfire risks. If the shrub cover is 50% or more, then there are two possibilities. If the coniferous midstory is 30% or more or if the height to the bottom of the canopy is less than 15 feet above the average shrub height in the stand, then use *Fuel Model 4* for dense tall shrubs and southern rough with ladder fuels or low canopy. Otherwise, use *Fuel Model 7* for southern rough if there is extensive shrub cover (50% or more) but no significant ladder fuels. If there is less extensive shrub cover that still covers at least 30% of the stand, use *Fuel Model sub-7* for low density southern rough. If the stand is a wetland, use *Fuel Model 8* for seasonally flooded swamps. In all other cases, use *Fuel Model 9* for mature forests.

5.1.4 SHRUB AND BRUSH MODELS

Stands with an extensive shrub layer can pose the greatest fire risk, since large amounts of fuel are available at the surface level. If the average shrub height of the stand is 6 feet or more and the management unit is a region that has pocosins, i.e. within the Southern Coastal Plains, use *Fuel Model 4* for very dense tall shrubs. A management unit is considered to be in a region with pocosins if it is in a Southern state and within 50 miles of the coast.⁹ Stands containing chaparral, pinebarrens, or jackpine should also use *Fuel Model 4* (Anderson 1982, p. 7), but these regions are not currently defined. If the stand is a forest with a predominantly coniferous *Composition*, use *Fuel Model 7* for southern rough. Otherwise, use *Fuel Model 6* for shrubs.

⁹ An exhaustive list of all Southern counties within 50 miles of the coast is recorded by the `fire_list/2` predicates in `fire_anderson.kb`. All of Florida is considered to be in the Southern Coastal Plains.

5.1.5 HERBACEOUS, AGRICULTURAL, URBAN, WATER, AND BARREN MODELS

Stands that are dominated by grasses and other herbaceous material are susceptible to wildfire but generally do not produce high fire intensities. Stands that are regularly maintained or contain no fuels rarely pose a serious fire risk. For forested stands with open canopies and few shrubs, there are two possible fuel models. If the total of the ground cover and the litter cover is 30% or more, use *Fuel Model 2* for open forest grasslands. Otherwise, if there is very little or no ground and litter cover, use *Fuel Model sub-2* for barren open forest. Barren open forest stands are unlikely to occur in untreated wildlands, but may result from regular prescribed burns or herbicide application. If the land cover type indicates a marsh, use *Fuel Model 3* for tall prairie and marshland grasses. If the land cover type indicates other herbaceous cover, use *Fuel Model 1* for grasslands. The marsh and herbaceous land cover types available in NED-2 are listed in Table 5-2. All other cases use degenerate *Fuel Model 0* for agricultural, urban, water, or barren stands.

Table 5-2: Marsh and herbaceous land cover types in NED-2.

Land Cover Type	Classification
'Wetlands (not including open water; palustrine wetlands only)'	Marsh
'Emergent wetland'	Marsh
'Scrub-Shrub wetland'	Marsh
'primarily herbaceous, non woody vegetation (75% or more cover)'	Herbaceous
'Herbaceous'	Herbaceous

5.2 ANDERSON WILDLAND RISK ASSESSMENTS

Long (2003) offers risk assessments for many of the Anderson fuel models. The NED-2 implementation of the Anderson model creates additional fuel sub-models to soften the risk assessment transitions between fuel model classifications. It also introduces a degenerate fuel model to cover *Very Low* risk agricultural, urban, water, and barren stands. Due to the qualitative nature of risk assessments, it is easy to provide risk assessments for the Anderson fuel models that are not described by Long. Table 5-3 gives a description of all Anderson fuel models, including several models not currently implemented in NED-2, along with the corresponding wildfire risks.

Table 5-3: Anderson fuel models, descriptions, and risk assessments.

Fuel Model	Cover Type Description	Risk
0	Agricultural, urban, water, or barren	Very Low
1	Grassland	Moderate
sub-2	Barren open forest	Low
2	Open forest grassland	Moderate
3	Marshland grasses, Tall prairie grasses	Moderate
4	Very dense tall shrubs, Southern rough w/ ladder fuels or low canopy	Very High
5	<i>Young green shrubs (not implemented)</i>	Moderate
sub-6	Moderate density immature hardwoods	Moderate
6	Shrubs, Dense immature hardwoods	High
sub-7	Low density southern rough	Moderate
7	Southern rough	High
8	Seasonally flooded swamp	Low
9	Mature forest	Low
10	<i>Heavy down / partial slash forest (not implemented.)</i>	Moderate
11	Light slash	High
12	<i>Moderate slash (not implemented)</i>	Very High
13	<i>Heavy slash (not implemented)</i>	Very High

5.3 COMMENTS

Some of the rules defining the Anderson fuel models may need to be refined. For example, at present, there are no NED-2 land cover types classified as seasonally flooded swamps. One or more of the marsh cover types may be better interpreted as swamps. It may be worth while to create a separate knowledge base, comparable to the forest *Composition* knowledge base, that contains rules to categorize the NED-2 land cover types as either forest, shrub and brush, grassland, marsh, swamp, agriculture, urban, water, or barren.

Many possible refinements or expansions of the fuel model rules would not lead to differences in wildfire risk assessments. For example, *Fuel Model 8* should include some of the non-flooded forests that are currently placed in *Fuel Model 9*. However, both models are given the same risk assessment. Such modifications can probably be neglected since they will have no effect on wildfire risk management. It may be worthwhile to simplify the Anderson risk model by removing some of the unnecessary distinctions between fuel models with the same risk assessment.

The Anderson risk model could easily be expanded to become an independent risk model with national applicability. Defining the regions outside of the Southern United States that contain plant communities for which *Fuel Model 4* applies would create a minimal such model. In addition to regions containing pocosins, Anderson includes regions containing chaparral, pinebarrens, and jackpine in *Fuel Model 4* (1982, p. 7).

A complete Anderson risk model would need to define the fuel models not covered by the procedure given by Long (2003). *Fuel Models 10, 12, and 13* represent higher wildfire risks for forested and logged stands. These would be especially relevant to a complete Anderson risk model for NED-2. Anderson (1982, pp. 14–16) offers simple rules to distinguish between the

additional slash models using transect data. The Hemel rule for *Medium Debris*, preferably an improved version, could perhaps distinguish between the mature forests in *Fuel Model 9* and the heavy down or partial slash forests in *Fuel Model 10*. *Fuel Model 5* for young green shrubs, which represents a decreased wildfire risk in shrub and brush stands, may be harder to implement.

CHAPTER 6

THE GIS AGENTS

A geographic information system (GIS) can display and analyze geographic data. NED-2 uses ESRI's ArcView GIS¹⁰ to create maps, which can display the values of virtually any stand- and MU-level goals and variables, and to automatically generate adjacency tables for the stands in the management unit. These functions are only available if the user has ArcView installed on their system and has shapefiles encoding geographic data for their management unit. There are two NED-2 GIS agents¹¹, one to create GIS displays and another to generate adjacency tables. The GIS agents utilize both components implemented in Prolog, which retrieve the NED-2 data, and components implemented in ArcView's Visual Basic for Applications (VBA), which actually create the GIS displays and calculate adjacency information.

6.1 THE GIS DISPLAY AGENT

The GIS display agent gathers together variable and goal data from NED-2 and displays it in ArcView. The agent is divided into two distinct components. The Prolog component (`arcview.dcm`) responds to requests on the blackboard to create GIS displays. It creates a database containing information about the plans and variables that the user has selected for display, prompts the user for a shapefile, and then activates the second component. The second component (`NED2VBA.mxd`) uses ArcView's VBA to actually create the GIS display.

¹⁰ NED-2 supports ArcView version 8.1 or higher. ArcView is a proprietary commercial product and is not distributed as part of NED-2. Contact ESRI to acquire ArcView (<http://www.esri.com>).

¹¹ Both GIS agents were developed by Hajime Uchiyama and have been maintained and modified by the author.

A GIS display can be created for any plan and year that has been simulated. In general, a GIS display contains multiple layers, where each **layer** encapsulates the data in a different view of the management unit. Each of the stands depicted in a layer can be colored according to the value of a variable for that stand. The GIS display can include layers for either all of the years in a single plan or all of the plans in a single year. For years that include treatments, layers for both the pre- and post-treatment views are included. The user can easily switch between different layers in the GIS display to see the effects of treatments or to compare the values of variables across different years or plans. This makes the GIS display a powerful visual analysis tool for land managers.

6.1.1 GIS DISPLAY PLANNING

Before a GIS display can be created, it must be planned. The planning is done by the reports planning agent (`reports_planner.dcm`). The reports planning agent is responsible for determining which views of the management unit and which goals and variables will be displayed. If the user selects any goals for display, the reports planning agent is responsible for requesting the necessary goal analyses before requesting the creation of the actual GIS display.

When a user requests a GIS display, the first thing that the reports planner does is to verify that ArcView is installed on the user's system and not currently running. Only one ArcView session can be open at a time. Then it opens the GIS analysis selection dialog (`gis_selection.dut`), shown in Figure 6-1. The GIS analysis selection dialog allows the user to select the type of GIS analysis and the goals and variables that will be displayed. If at least one plan has been simulated, the analysis types available for the display are for a single plan across multiple years or a single year across multiple plans. If a baseline has been generated, it

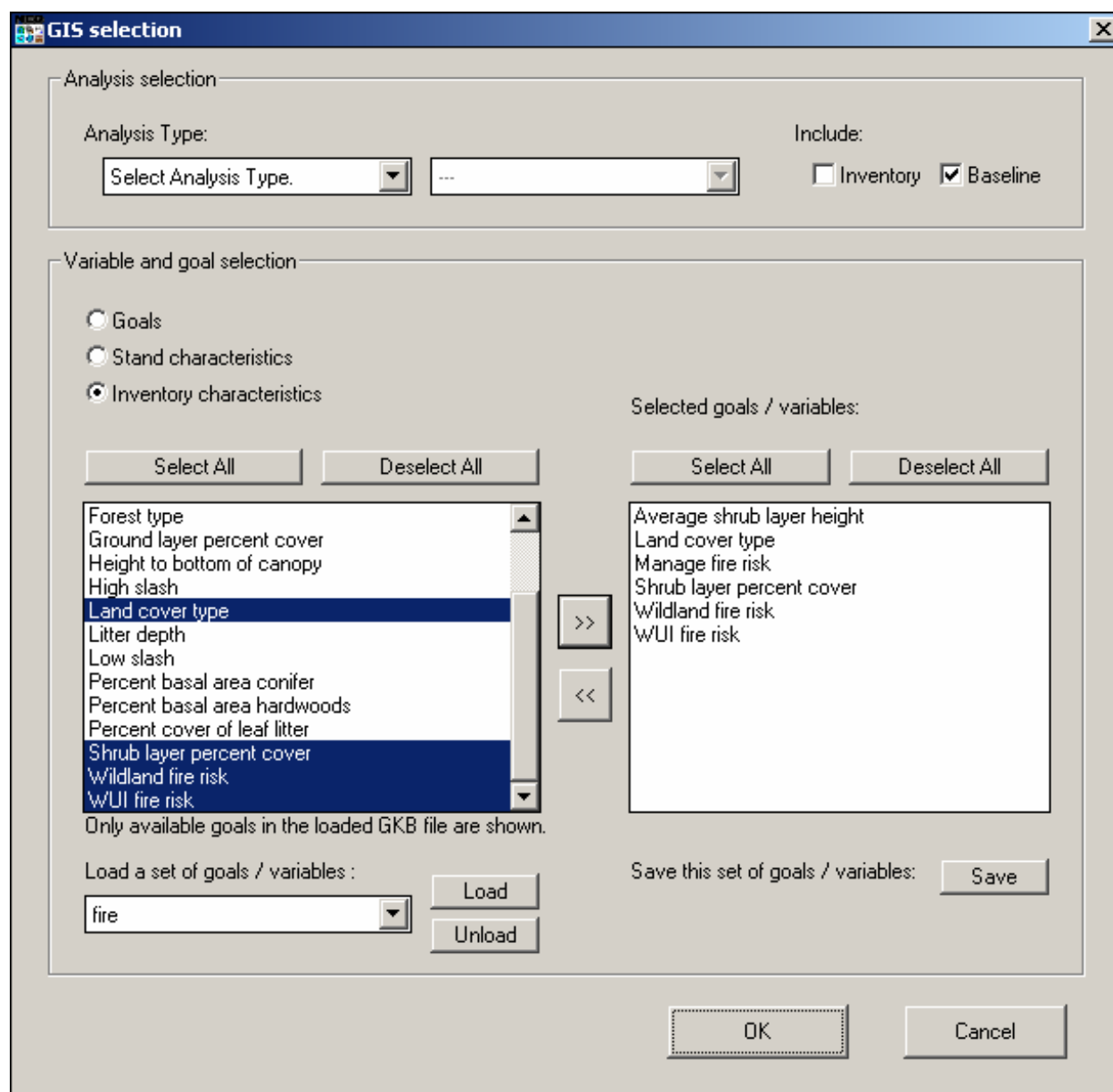


Figure 6-1: The GIS analysis selection dialog.

can be included in the display as well. Whether or not a plan or baseline has been simulated, the user can always create a display for the inventory data.

Variables and goals are selected by moving them from the lists of available goals and variables located on the left to the list of selected items located on the right. Items are moved between the two boxes by using the '>>' and '<<' buttons. To aid the user in finding the desired item, the items available for display are divided into three categories: goals, stand characteristics, and inventory characteristics. Inventory characteristics include the variables describing the vegetation on a stand, whereas stand characteristics cover the non-vegetative variables. Only the goals that have already been selected in planning are available for GIS analysis selection. The user can switch between categories by using radio buttons. Changing categories will not affect items already selected.

The user can save, load, and unload sets of goals and variables. They are saved as GIS knowledge base files (GKBs). GKBs act as filters on the lists of available goals and variables and allow the user to find frequently used goals and variables more easily. Again, only the goals in the GKB that have already been selected for the management unit are available for selection. Selecting a GKB filter does not affect items that have already been placed in the selection list. Newly saved GKBs are automatically placed in the dropdown box at the bottom left. The user can also load previously saved GKBs and unload GKBs that are currently in the dropdown box. The dropdown box lets the user easily switch between any loaded GKBs and the full list of available goals and variables. GKBs remain loaded throughout a NED-2 session. In Figure 6-1, a GKB file, `fire.gkb`, containing all of the variables related to fire risk has been loaded.

The GIS analysis selection dialog returns a list of all selected views, an unsorted list of all selected goals and variables, and a list of all selected goals sorted by their resource categories.

The reports planning agent queries the user for the shapefile for the management unit, posts requests for analysis of the selected goals on all of the selected views, and posts a request for the creation of a GIS display. The GIS display request includes the list of all selected goals and variables, a list of all snapshots in the selected views, and the location of the shapefile for the management unit.

6.1.2 THE GIS DISPLAY AGENT AND THE ARCVIEW DATABASE

The Prolog component of the GIS display agent (`arcview.dcm`) responds to requests on the blackboard to create GIS displays and gathers all of the data from NED-2 necessary to create a GIS display in ArcView. The data is placed in a database that is used by the VBA component. The ArcView database contains information about the views and variables selected for the display. The Prolog component also creates a small text file (`arcview_def.txt`) used by the VBA component to find the ArcView database, the shapefiles for the management unit, and custom color definitions for NED-2 displays.

The ArcView database (`ArcViewTable.mdb`) contains a table with information about the selected views, a table with meta-information about the goals and variables selected for display, and separate tables for each view containing the values of the goals and variables for the view. The [`Plan_Table`] table merely specifies names for the selected views. Each view is given a distinct name with the format *plan_year_pre/post*, where *plan* is the name of the plan for the view, *year* is the year of the view, and *pre/post* either is `Pre_treatment` or `Post_treatment` if there is a treatment in that year of the plan or is blank if there is not treatment that year.

The [`Var_Table`] table contains meta-information about the selected goals and variables. For each goal and variable, there is an entry with the name used in the database, the descriptive

name used for display, the type, and the units. Variable types are either **NUMERIC**, **BOOLEAN**, or **STRING**. Goals have the type **GOAL**.

The [*plan_year_pre/post*] table for each view contains the values that will be used to color the stands in the layer for the view in the GIS display. The table contains the CF for each goal and the value for each variable for each stand in the view. In order for MU-level goals to be displayed, the CF for the MU-level goal is assigned to each individual stand.

6.1.3 THE GIS DISPLAY AGENT AND THE ARCVIEW VBA CODE

When the ArcView database is completed, the ArcView VBA code (*NED2VBA.mxd*)¹² is executed to create the GIS display. The VBA code loads the ArcView database, uses the geographic data in the shapefiles to create a layer for each view in the [*Plan_Table*] table, and joins the geographic data in each layer to the variable data in the [*plan_year_pre/post*] table for the corresponding view.

The GIS variable selection dialog, shown in Figure 6-2, then opens, allowing the user to select a particular goal or variable to display. If the selected variable is numeric, the values for the stands must be partitioned before they can be displayed. Each partition will be assigned a distinct color. At present, only equal interval partitioning of data is supported in the GIS variable selection dialog. The user can select the number of classes into which the data will be partitioned. They can also select the range for the partitions, either from the minimum to the maximum value in the data or from 0 to the maximum value. For non-numeric variables, each distinct variable value will be assigned a distinct color.

¹² To edit or debug the VBA code, open the code, either by double-clicking the file or generating a GIS display, and open the 'Tools' menu. Go to 'Macros' then to 'Visual Basic Editor'.

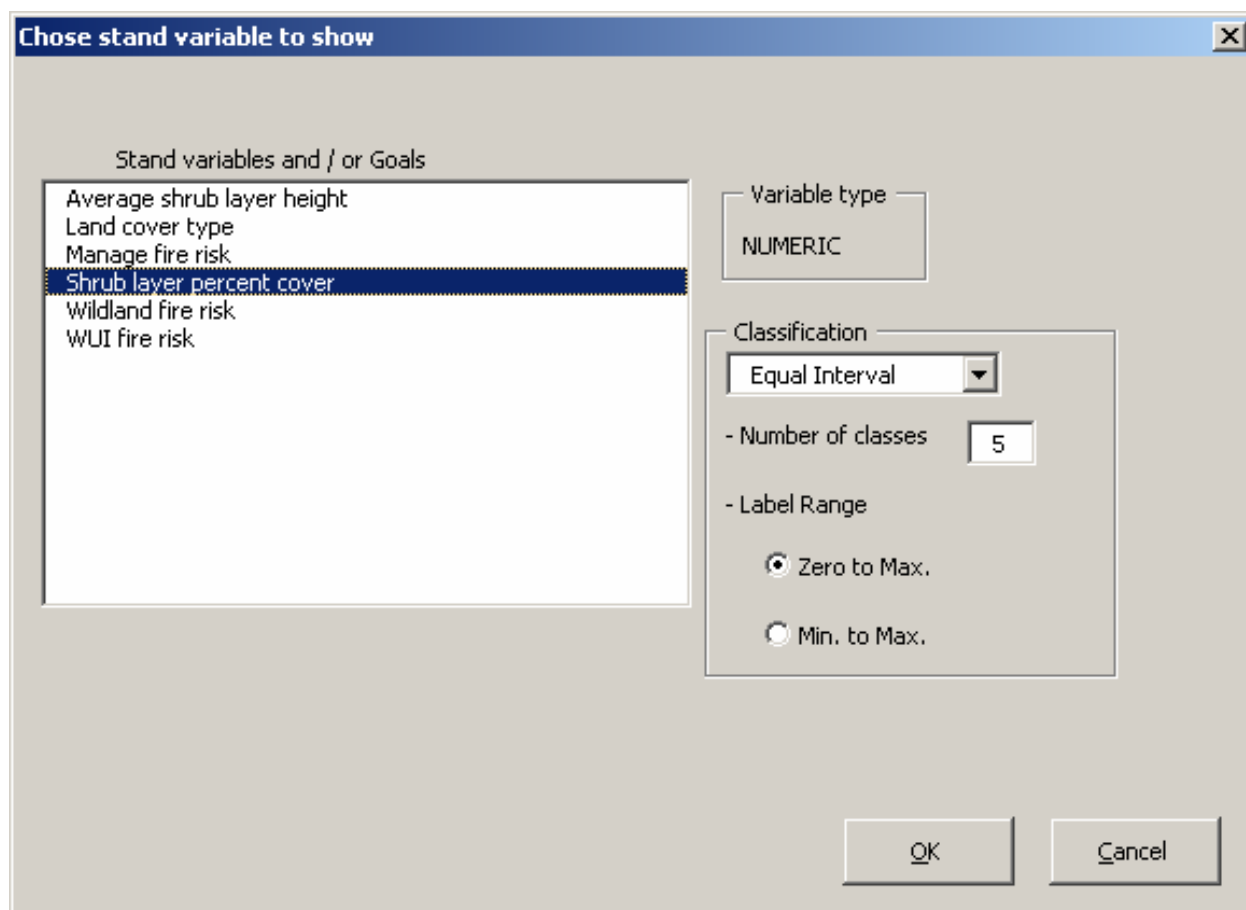


Figure 6-2: The GIS variable selection dialog.

Once the user makes their variable selection, a renderer is called to create the GIS display. Separate renderers are implemented for each type of variable: numeric, string, Boolean, and goal. The numeric renderer colors the layers from yellow to red according to the partition selected by the user. The string renderer assigns a random color to each distinct string. The Boolean renderer assigns green to *true* and red to *false*. The goal renderer assigns colors according to the CF of the goal analysis: *failed* is red, *barely failed* is pink, *barely passed* is light green, and *passed* is green.

The custom colors used by the renderers are defined in the color definition file (`ColorDef.ini`). To define additional custom colors, specify the variable type, the variable value, and the RGB values for the color. Custom colors are defined for wildfire risk assessments. The five risk assessments from *Very Low* to *Very High* use blue, green, yellow, orange, and red, respectively. Lighter versions of these colors are used for worst-case scenario assessments.

After the display is rendered, it is modified to show only one layer at a time, and the legend is added to the top layer. A GIS can display multiple layers simultaneously, one overlaid on another. Each layer typically encapsulates information about different elements in the same geographic region, for example, roads and rivers. There is no inconsistency in displaying these simultaneously. The layers used in GIS displays for NED-2 encapsulate information about the same elements but for different years or management plans; so only a single layer is visible at a time.

Even with a full map of the management unit displayed, it can be difficult to visually navigate if the individual map polygons are not labeled. To add labels to a layer, right-click on the layer heading in the left pane of the ArcView window and select 'Label Features'. If no labels appear or different labels are desired, right-click on the layer heading, select 'Properties',

go to the 'Labels' tab, and choose a label from the 'Set Label Field' dropdown box. For example, selecting 'view.STAND_ID' will label each stand with the stand name.

The user can switch between layers by using the checkboxes by the layer headings in the left pane of the ArcView window. Multiple layers can be selected, but only the top layer will be visible. To avoid confusion, it is advisable to select only one layer at a time. Changing layers can cause a problem updating the legend; a button is included on the NED Renderers toolbar, shown in Figure 6-3, to address this problem. The second button on the toolbar redraws the legend. When the user is finished analyzing the current display, the third button on the toolbar will bring up the GIS variable selection dialog again, and another variable can be selected.



Figure 6-3: The NED renderers GIS toolbar.

6.1.4 SAMPLE GIS DISPLAYS

Sample GIS displays are shown in Figures 6-4 – 6-8. These sample displays use the wildfire risk management domain¹³ to highlight the GIS rendering of different variable types. Figure 6-4 shows the shrub layer percent cover of the stands. This is a numeric variable that has been partitioned into five classes. The majority of the management unit has little shrub cover, but some stands have moderate levels.

¹³ The management unit used for these displays is a real management unit with real inventory data that has been modified to test wildfire risk models.

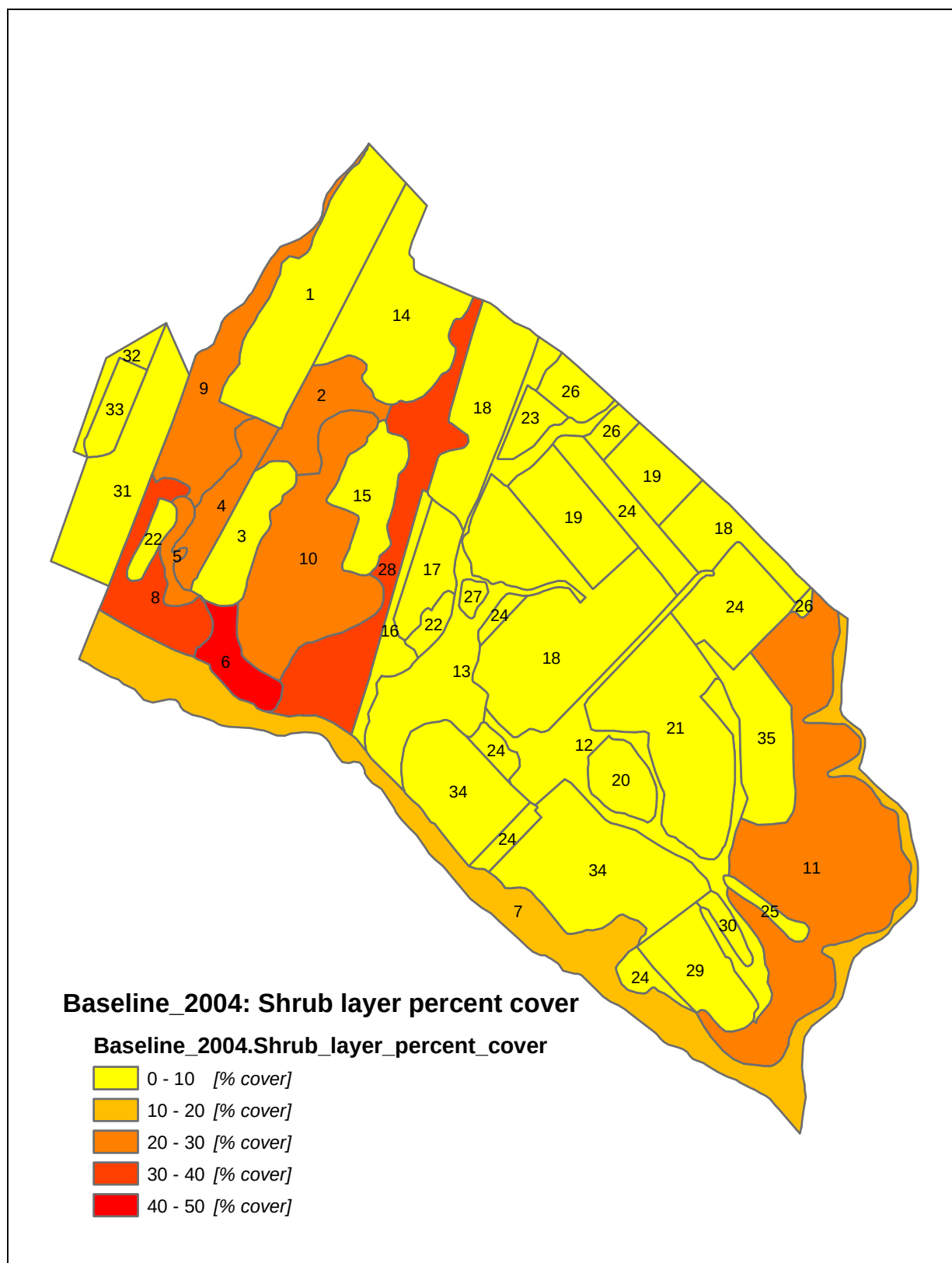


Figure 6-4: A sample GIS display: shrub layer percent cover.

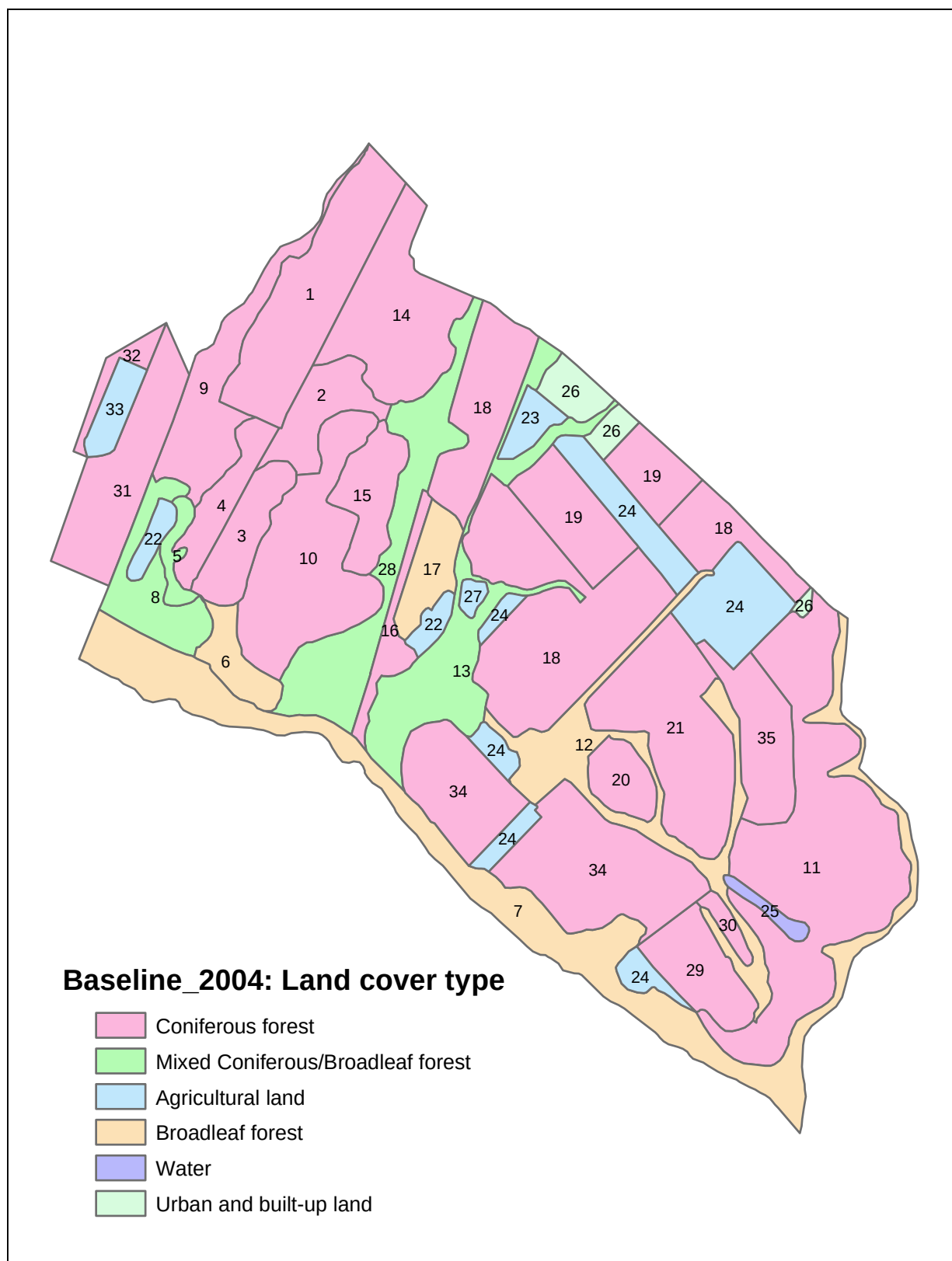


Figure 6-5: A sample GIS display: land cover type.

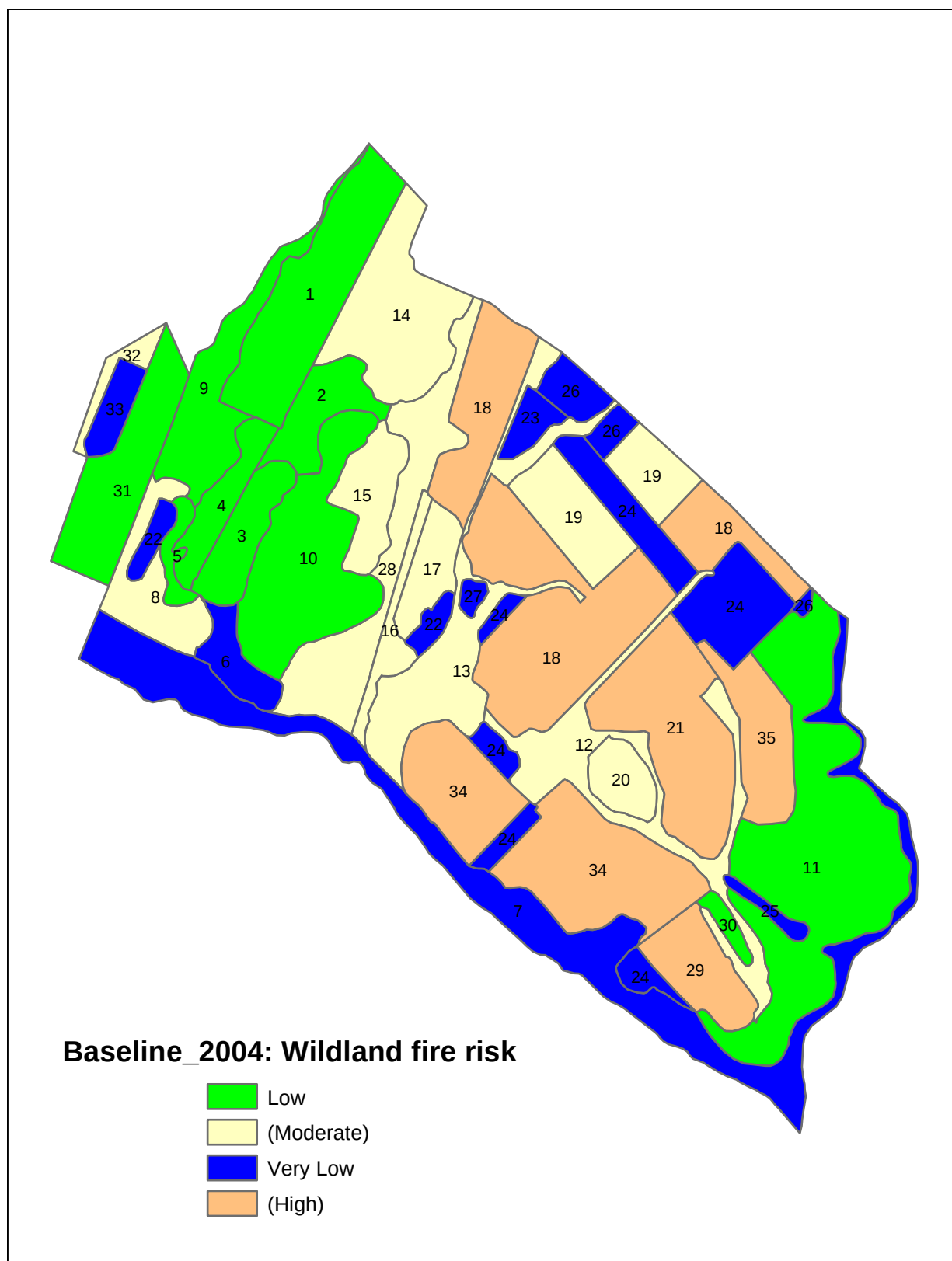


Figure 6-6: A sample GIS display: wildland fire risk.

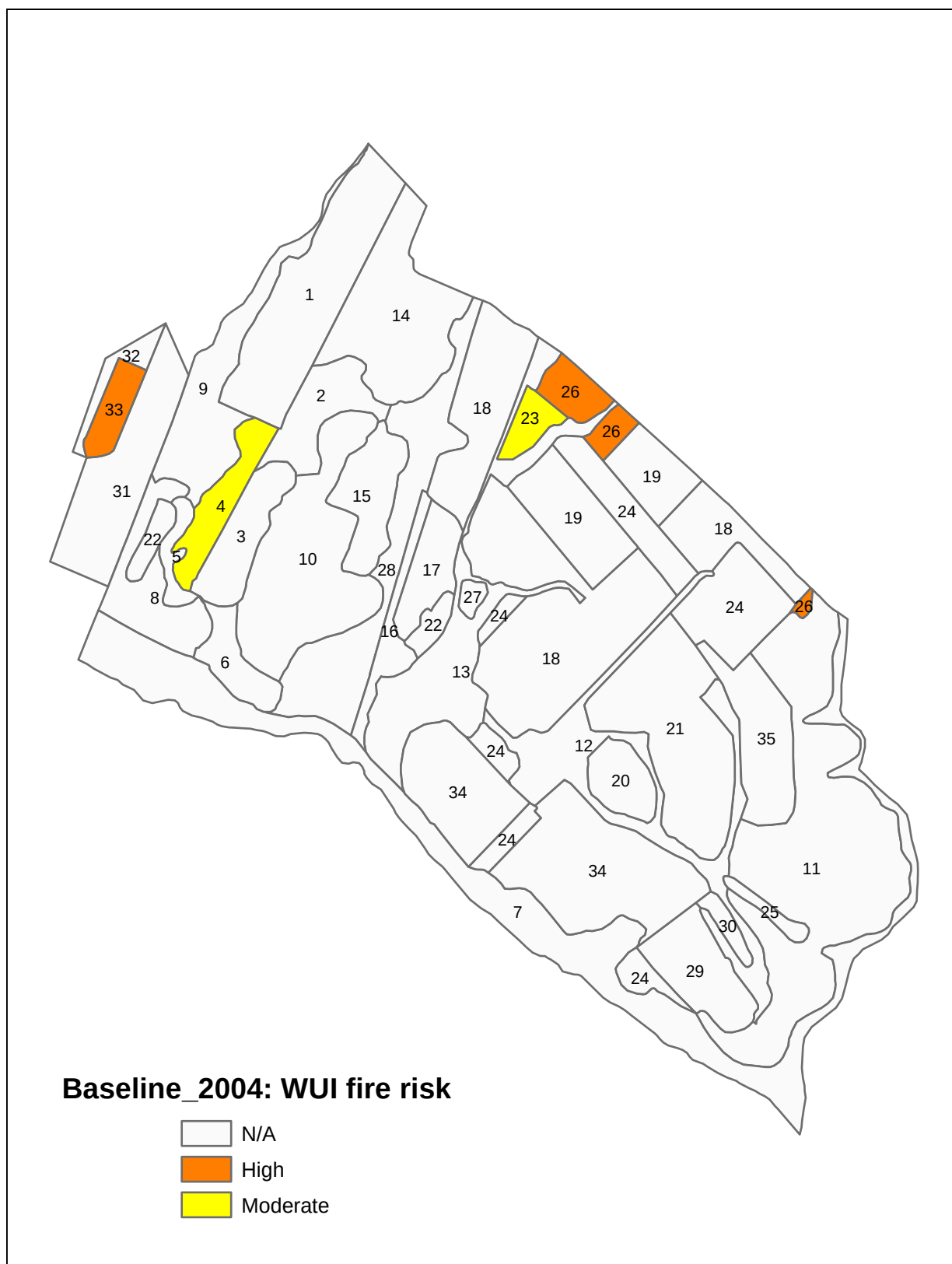


Figure 6-7: A sample GIS display: wildland-urban-interface fire risk.

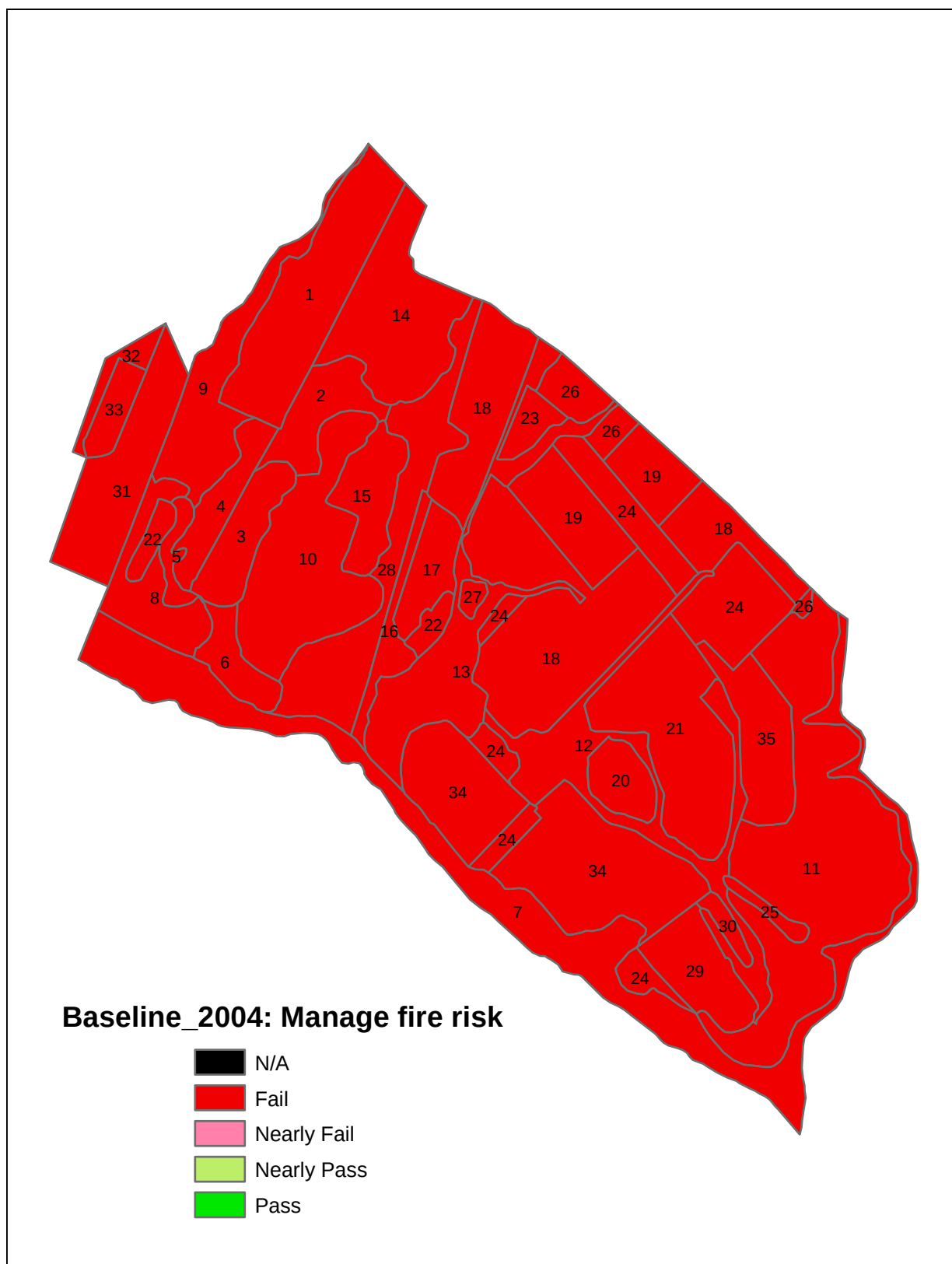


Figure 6-8: A sample GIS display: manage fire risk.

Figure 6-5 shows the land cover types of the stands. This is a string variable. Each land cover type is assigned a random color from the default pallet. The majority of the stands are coniferous forest. There are also a number of mixed and broadleaf forest stands. The management unit also includes agricultural, urban, and water stands.

Figure 6-6 shows the wildland risk assessments of the stands. This is a string variable that uses a custom pallet defined in the color definitions file (`ColorDef.ini`). The blue stands have *Very Low* fire risk and the green stands have *Low* risk. The light yellow and light orange stands represent worst-case scenarios for potentially *Moderate* and *High* risk, respectively. All of the agricultural and urban stands, as well as a few broadleaf stands, have *Very Low* risk. A large patch of conifers has *Low* risk, while numerous other coniferous stands have potentially *High* risk. Figure 6-7 shows the wildland-urban-interface risk of the stands. This is another string variable using the custom risk assessment pallet. Most stands do not have buildings. Those with buildings have either *Moderate* or *High* WUI risks.

Figure 6-8 shows the satisfaction of the *Manage Fire Risk* goal. This is a goal variable. Note that the full list of goal satisfaction levels is included in the legend. The management unit fails the goal. This is clearly due to the presence of *High* WUI risk stands and the prevalence of potentially *High* wildland risk stands.

6.2 THE GIS ADJACENCY AGENT

The GIS adjacency agent uses the geographic information in a shapefile to generate adjacency tables for management units. Several NED-2 goals rely on adjacency relations between stands. For example, one of the DFCs for the *Manage Fire Risk* goal uses adjacencies directly, while another DFC utilizes WUI risk assessments that might require adjacencies as

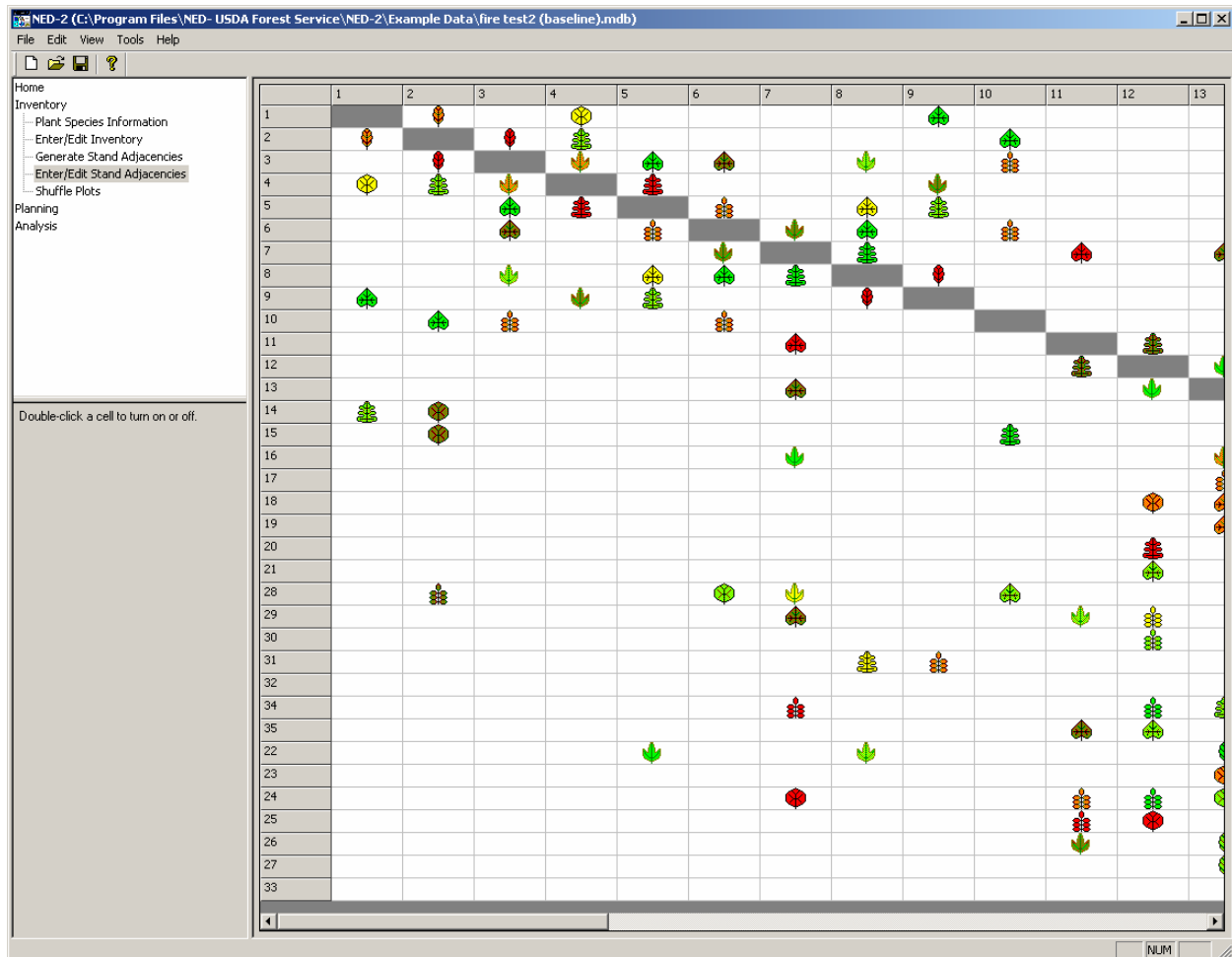


Figure 6-9: The NED-2 enter/edit stand adjacencies table.

well. Figure 6-9 shows the table, accessible in the NED-2 interface, that allows users to manually enter or edit stand adjacencies. Icons of different shape and color represent the individual adjacencies.

Although this table can be used to enter adjacencies manually for management units of any size, it becomes increasingly impractical as the number of stands increases. The adjacency table shown in Figure 6-9 is for a management unit with 35 stands. There are 182 actual and 1190 possible adjacency relations. The largest management unit tested in NED-2 has 500 stands with 2240 actual adjacencies. Some stands have several dozen adjacents. The adjacency table for this management unit has almost 250000 cells representing possible adjacencies. It is likely that manual data entry in a table that large will be both unreliable and intolerable.

The GIS adjacency agent automatically generates the adjacency table. The Prolog component (`adjacency.dcm`) responds to the request for adjacency generation, checks that ArcView is installed on the user's system, prompts the user for a shapefile, and calls the VBA component (`autoAdjacentCalc.mxd`).¹⁴ All of the work is done by the VBA component.

The VBA component connects to the NED-2 inventory database, clears any existing adjacency entries, and sets the adjacency source codes to '0', i.e. empty (NED-2 source codes are covered in Chapter 7). The number of polygons in the map of the management unit is obtained from the DBF table in the shapefiles, and a timer is started to provide estimates of the time remaining in the calculation.

For each polygon in the map, the progress bar is updated, and the adjacencies for the polygon are calculated from the shapefile.¹⁵ Stands may be represented by multiple polygons. The adjacency calculation gets all of the points in the polygon and compares them to all of the

¹⁴ To edit or debug the VBA code, request adjacency generation in NED-2, hit Ctrl+Break, and select 'Debug'.

¹⁵ The code for calculating the adjacencies for a polygon was developed by Ramyaa.

points in every other polygon. The adjacencies are added to the database for the stand represented by the polygon and the source code for the adjacencies is set to '5', i.e. calculated outside of NED-2.

For a yet to be determined reason, the adjacency calculation does not yield symmetric results for some shapefiles. Clearly, adjacency is a symmetric relation. So, not only are the polygon's adjacents recorded for the polygon's stand. That stand is added to the database for each of its adjacents as well. This forces symmetry in the calculation but creates some inefficiency. The estimated time remaining is then updated in the progress bar and the calculation moves on to the next polygon.

Since stands may be represented by multiple polygons, the raw adjacency results may include multiple instances of adjacent stands and may even indicate that a stand is adjacent to itself. All multiple and self-referential entries in a stand's adjacents are cleaned up after all polygons have been processed. Finally, ArcView is shut down¹⁶ and control is returned to the NED-2 interface.

The results from the GIS adjacency agent appear to be complete and correct. The agent accounts for any asymmetry in the core calculation, it can handle stands represented by multiple polygons, and it is not affected by polygons in the shapefile that do not correspond to known stands in the NED-2 inventory. Despite some inefficiency in the code, the agent can produce the adjacency table for management units with a few dozen stands in under a minute. The adjacency calculation for the 500-stand management unit mentioned above took several hours. The results of this particular calculation have not been exhaustively verified. At present, there is still a shapefile for a very small management unit¹⁷ for which the adjacency calculation will not

¹⁶ To aid in editing and debugging, comment out the call to 'CloseDocument' in start_main().

¹⁷ The McKnight management unit.

produce results. This merits investigation to determine whether the failure is due to the adjacency calculation code or to corruption of the shapefile, which produces no errors when used for GIS displays.

6.3 FUTURE DIRECTION

As just indicated, there may still be errors in adjacency generation that warrant investigation. There is also some motivation to try to speed up the adjacency calculation. Efficiency of the calculation is only a minor consideration, however, since the calculation only needs to be performed once for a management unit.

Most of the future work that could be done with the GIS agents will likely focus on the GIS display agent. Apart from the aforementioned problem with the legend when switching between layers, the GIS display agent functions properly. The legend problem can easily be fixed by using the redraw the legend button on the NED Renderers toolbar. It would be preferable, however, to have the legend be redrawn automatically.

A simple and desirable addition to the GIS display agent would be to allow custom minimum and maximum values to be used when partitioning numeric data. It may also be useful to implement the other types of partitions supported by ArcView. Currently only equal interval partitions are available in the GIS variable selection dialog. For seasoned users of ArcView, these additions are unnecessary; partitions for each layer can be set in the 'Properties' dialog.

The most crucial work that needs to be done on the GIS display agent is cleaning up the `arcview.dcm` code. The file contains large sections of legacy code that no longer appear to be in use, and several frequently used predicates could likely be made more efficient.

CHAPTER 7

MODIFICATIONS TO THE NED-2 BLACKBOARD

The key to the modularity of NED-2 is the use of a blackboard architecture, which allows every module access to all data of system-wide interest. Modules do not directly interact with one another; they interact indirectly through the blackboard. Queries to the NED-2 blackboard use the `known/1` predicate, which has the form

`known(Attribute(Object, Value)),`

where the `Value` for the specified `Attribute` and `Object` is returned. This single query puts the facts in the working memory of Prolog on par with the data in the NED-2's MS Access databases.

The `known/1` predicate has four methods of retrieving the value for a specified object and attribute. It looks for a value stored as

- 1) a simple fact asserted by an agent as a Prolog clause,
- 2) static meta-data stored as a Prolog clause,
- 3) a simple fact located in a database, or
- 4) a derived fact.

NED-2 agents send values to one another by asserting simple facts, and all results from the NEDCF inference engine are asserted as simple facts. Static meta-data contains meta-knowledge that will not change from session to session, for example, information about numeric units and conversions. The NED-2 databases contain inventoried and simulated data about management

units, data about plant species, and data about the variables, goals, and reports used in NED-2. For all but the derived facts, the value is already determined and directly retrievable from the blackboard.

Two modifications to the NED-2 blackboard were necessary to create fully functional wildfire risk models. The re-introduction of derived facts activates the NED-2 blackboard by creating intelligent behaviors to respond to queries. The implementation of source code checking for queries to the NED-2 databases imposes a constraint on the blackboard but ensures the quality of the retrieved data.

7.1 SOURCE CODE CHECKING

Data in the NED-2 databases for management units utilize **source codes** to determine the circumstances in which values of variables can be altered. The NED-2 source codes are listed in Table 7-1. Variables cannot be altered if it will lower their source codes. For example, a calculated value would have a source code of '4', so it could not, in general, replace a value entered by the user, which has a source code of '7'.¹⁸

Although the NED-2 interface and DLLs checked the source codes of data, source code checking was not implemented in the Prolog blackboard's use of `known/1`. This led to problems in the implementation of the wildfire risk models. Numeric attributes, like slope and aspect, are required to have numeric values in the database, even if their values have not been inventoried by the user and are not defaulted. Values of '0' were assigned to these attributes, which were actually unknown. Values of '0' for the source codes of these attributes specified that they were in fact unknown, but when `known/1` queried the database, it did not check the source codes, and it returned the value of '0' for these attributes.

¹⁸ For the crucial attributes *forest type* and *land cover type*, the user's values can be replaced by calculated values.

Table 7-1: NED-2 source codes.

Source Code	Description
0	empty
1	default
2	default other
3	default user
4	calculated
5	calculated outside NED
6	imported
7	user
8	model
9	program
10	absolute

It may seem desirable to leave unknown values blank. This, however, would not suffice. A blank cell could still be misinterpreted. Consider stand adjacencies. If adjacencies have not been entered or automatically generated, then the cell would be blank. Also, if the stand were not adjacent to any other stands, then the cell would also be blank. One null cell would be meaningful while the other would not. Special values could be entered in such cases, for example, a ‘-1’ for the adjacency data, since all stands are assigned non-negative numbers. However, a ‘-1’ might be meaningful in the context of a different attribute. Using other numbers and symbols can reduce the likelihood that they will be needed as actual data values, but it seems impossible to decide on a value that will never be interpreted as meaningful in any context.

The best solution is to implement source code checking. Source code checking is implemented in the `database_fact/4` predicate (`sql.dst`) called by `known/1` to access the NED-2 databases. It can be toggled on and off by asserting and retracting the flag

`ned2_source_codes(true).`

By default, the flag is asserted and source code checking is used by the NED-2 blackboard. In

order to check the source codes, the predicate `database_fact_check_source/2` adds 'source_' to the beginning of the attribute, queries the database for the value of the source, and checks that it is not '0'. Attributes used as keys in the database like the unique number assigned to each stand and snapshot, which are automatically generated by NED-2, have no source codes. If the attribute has no source code or the source code is not '0', then the `database_fact_check_source/2` predicate succeeds and the value of the attribute is returned. If the source code is '0', then 'no data' is returned as the value of the attribute.

With source code checking activated, only verified values for the object and attribute directly queried will be returned. However, source code checking is not performed for indirect queries. It is possible to use aggregated database functions in a query, for example `MIN` for the minimum value of all matching objects or `COUNT` for the number of matching objects. In such cases, the values in the database are indirectly accessed and no source code checking is performed. Also, it is possible to use unbound constraints in the definition of an object. The values of these constraints will be indirectly accessed and bound during the query. Again, no source code checking is performed during the binding of such constraints.

7.2 DERIVED FACTS AS ACTIVE BLACKBOARD BEHAVIORS

The methods for retrieving simple Prolog facts, meta-data, and simple database facts are **passive methods**; they merely retrieve values that are explicitly stored on the blackboard. The method for retrieving derived facts is an **active method**; the value of a **derived fact** must be calculated before it is returned. This can range from a simple mathematical calculation to a complex calculation involving external models and programs. Since the value of a derived fact is not known at the time of the query, the derivation of the value can be considered a behavior of an

active blackboard. The blackboard does not merely store facts; by using derived facts it can actively deduce new facts from those already known.

Arguably, the NED-2 blackboard is active even without the use of derived facts, since the blackboard selects the appropriate method to retrieve data from diverse sources – simple facts, meta-knowledge, and databases. Nevertheless, the values are explicitly stored in these sources; the blackboard merely uses an assortment of methods to find them. At best, this can be considered a **weak active blackboard**. Queries to the databases can use aggregate functions like MIN, MAX, or COUNT. Admittedly, the values returned by such queries are not explicitly stored in the database; they must be calculated. However, the values are calculated by the database, not by the blackboard itself. So, the derivation of these values cannot be attributed to the blackboard.

Derived facts offer the only method that can be considered as creating a **strong active blackboard**; derived facts are components of the blackboard itself that are capable of deriving new values from explicitly known data. Each derived fact implemented in NED-2 creates a new intelligent behavior that the blackboard has at its disposal. Consider again the wildfire risk assessment behaviors (`fire_variables.dut`), which respond to a standard blackboard query for wildland or wildland-urban-interface risk assessments. The risk assessment behaviors determine the appropriate model for the current management unit, load the corresponding knowledge bases, call the NEDCF inference engine, store the risk assessment returned as a new fact on the blackboard, and return the value for the query. These behaviors demonstrate that the blackboard can possess an active, deliberative agency in addition to its more typical passive, reactive methods for data retrieval.

Apart from the new derived facts implementing wildfire risk assessments, a number of derived facts used to perform simple mathematical calculations are included in NED-2

(`derived_facts.dut`). These are designed to calculate values that have been removed from the databases. However, the vast majority of these derived facts appear to be no longer functional. Nearly all of them call an apparently non-existent predicate, `current_snapshot_list/1`, to obtain the snapshots used in their calculations. It is likely that this entire file is legacy code left over from NED-1.

7.3 DERIVED FACTS AND GIS DISPLAY

The primary benefit of using derived facts in place of custom Prolog clauses to derive values is the ability to use them in a transparent and modular manner; they are accessed by a standard blackboard query. Custom clauses are just as capable of deriving values, but they lack a common modular format that can be used in a concise manner by other agents, in particular the GIS display agent.

Several changes had to be implemented to make GIS display of derived facts possible. For starters, the reports planning and GIS display agents need to know that the attribute determined by the derived fact is available for display. Typically, attributes are available for GIS display because they are in certain tables in the database for the management unit. The particular table determines the category that the attribute is listed under: goal, stand characteristic, or inventory characteristic. Also, the GIS display agent needs the name, units, and variable type of the attribute for use in the ArcView database. By including this meta-data along with a derived fact, it becomes available for inclusion in a GIS display. The meta-data is encoded in the `derived_fact_schema/5` predicate. Collectively, these predicates form a virtual database, comparable to the `NED_variables.mdb` database, which store the meta-data for derived facts.

Derived facts seemed to be the best way to implement the wildfire risk assessments used in the *Manage Fire Risk* goal (`fire_variables.dut`). The degree to which the goal is satisfied is important data. This is what is determined by the wildfire risk analysis agent and posted to the blackboard. But it seemed that the actual risk assessments of the buildings and stands were the data most relevant in developing a treatment plan to manage wildfire risk. This data was buried inside the goal analysis and not easily accessible outside of the scope of the risk analysis. By implementing the risk assessments as derived facts, they are on the blackboard for any agent to use. Not only do they become more accessible for hypertext reports this way, they are also available for use in GIS analysis.

Several other attributes used in NED-2 goals may be better implemented as derived facts. For example, the wildlife and timber goals each rely on custom forest types. A user attempting to satisfy one of these goals may wish to perform a GIS analysis to aid in the development of an appropriate treatment plan. Since these custom forest types are currently fully embedded in the knowledge bases that implement the DFCs for the goals, they are not available for GIS display. Also, a wildfire risk consultant may be interested in the Anderson fire behavior fuel model for a stand. If the Anderson fuel model were implemented as a derived fact, then it could be used in a GIS display.

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APPENDIX A

QUICK REFERENCE GUIDE: THE LONG WUI RISK MODEL

Figures A-1 – A-6 offer a quick reference guide for determining Long WUI risk assessments from NED-2 inventory data. The Long (2003) wildland-urban-interface risk model assigns qualitative wildfire risk assessments to buildings. Risks are *Low*, *Moderate*, *High*, or *Very High*. Risk assessments are determined by assigning risk factor points for the hazardous fuels in the wildland area surrounding and for the structural hazards inherent in the building. The total risk points are used to assign a risk assessment.

Rule Structure:

- *Hazardous fuels points* = *Adjacent area hazard pts.* × *Defensible space pts.*
- *Structural hazard points* = *Firebrand ignition pts.* + *Indirect ignition pts.* + *Direct ignition pts.*
- *Total Risk Points* = *Hazardous fuels points* + *Structural hazard points*

Risk Assessment:

Total Risk Points	WUI Fire Risk.
> 13	Very High
9-13	High
5-8	Moderate
< 5	Low

Figure A-1: The Long WUI fire risk assessment rule.

Rule:

- IF the *land cover type* is urban or agricultural:
 'Urban and built-up land',
 'Residential',
 'Commercial, Services & Institutional',
 'Industrial',
 'Transportation, Communication and Utilities',
 'Industrial/Commercial complexes',
 'Mixed urban or built-up land',
 'Other urban or built-up land',
 'Agricultural land',
 'Cropland and pasture',
 'Orchards, bush fruits, vineyards, nurseries & ornamental horticulture',
 'Confined feeding operations', or
 'Other agricultural land',
 THEN use the maximum *Anderson Wildland Risk* of all *adjacent stands*,
- OTHERWISE, use the *Anderson Wildland Risk* of the stand containing the building.

Point Allocation:

Wildland Risk	Adjacent Area Hazard Pts.
Very High	5
High	4
Moderate	2
Low	1
Very Low	0

Variable Usage:

Description	Inventory Location	Program Code
Land cover type	Stands: ID: inventory	stand_cover_type
Adjacent stands	<i>Enter/Edit Stand Adjacencies</i>	stand_adjacents
Anderson wildland risk	<i>Calculated (see Ch. 5; Appendix C)</i>	fire_anderson

Figure A-2: The Long adjacent area hazard rule.

Point Allocation:

Defensible Space	Defensible Space Pts.
< 30 ft.	4
30-60 ft.	2
60-100	1.5
> 100	1

Variable Usage:

Description	Inventory Location	Program Code
Defensible space	Stands: ID: inventory: buildings	building_defence

Figure A-3: The Long defensible space rule.

Rule:

- Use only the highest rated firebrand ignition factor.

Point Allocation:

Firebrand Ignition Factors	Firebrand Ignition Pts.
Wood shingles or shakes	5
Wood deck	3
Open soffits	3
Open foundation	3
None of the above	0

Variable Usage:

Description	Inventory Location	Program Code
Wood shingles or shakes	Stands: ID: inventory: buildings	building_shingles
Wood deck	Stands: ID: inventory: buildings	building_deck
Open soffits	Stands: ID: inventory: buildings	building_soffits
Open foundation	Stands: ID: inventory: buildings	building_foundation

Figure A-4: The Long firebrand ignition factors rule.

Rule:

- Use only the highest rated indirect ignition factor.

Point Allocation:

Indirect Ignition Factors	Indirect Ignition Pts.
Slope > 30%	2
Wood fence	2
Adjacent building < 50 feet	1
Stacked firewood	1
None of the above	0

Variable Usage:

Description	Inventory Location	Program Code
Slope > 30%	Stands: ID: inventory: buildings	building_slopes
Wood fence	Stands: ID: inventory: buildings	building_fence
Adjacent building	Stands: ID: inventory: buildings	building_adj
Stacked firewood	Stands: ID: inventory: buildings	building_firewood

Figure A-5: The Long indirect ignition factors rule.

Rule:

- IF the building has *defensible space* of 100 feet or less,
THEN use only the highest rated direct ignition factor,
- OTHERWISE, *Direct Ignition Pts.* = 0.

Point Allocation:

Direct Ignition Factors	Direct Ignition Pts.
Wood siding	3
Vinyl siding or soffits	2
Single paned, non-tempered windows	2
None of the above	0

Variable Usage:

Description	Inventory Location	Program Code
Defensible space	Stands: ID: inventory: buildings	building_defence
Wood siding	Stands: ID: inventory: buildings	building_wood_siding
Vinyl siding or soffits	Stands: ID: inventory: buildings	building_vinyl_siding
Single paned, non-tempered windows	Stands: ID: inventory: buildings	building_windows

Figure A-6: The Long direct ignition factors rule.

APPENDIX B

QUICK REFERENCE GUIDE: THE HEMEL WILDLAND RISK MODEL

Figures B-1 – B-10 offer a quick reference guide for determining Hemel forest risk variables. Risk assessments corresponding to these variables can be found in Table B-1.¹⁹ The Hemel wildland risk model (2004) assigns qualitative wildfire risk assessments to stands. Risks are *Very Low*, *Low*, *Moderate*, *High*, or *Very High*. Risk assessments for forested stands are determined by calculating the values for eight model variables: *Composition*, *Landform*, *Aspect*, *Slope*, *Canopy Structure*, *Litter*, *Debris*, and *Ladder Fuels*. The risk assessment is obtained by matching these values to the appropriate row in a lookup table. Risk assessments for non-forested stands are determined by the Anderson wildland risk model (see Chapter 5; Appendix C).

¹⁹ Entries in the forest risk table are numbered according to the row numbers in the spreadsheet supplied by Hemel.

Rule:

- IF the *land cover type* is 'Broadleaf forest' or 'Forested wetland',
THEN the *Composition* is **Hardwood**.
- IF the *land cover type* is 'Coniferous forest',
THEN the *Composition* is **Pine**.
- IF the *land cover type* is 'Mixed Coniferous/Broadleaf forest',
THEN
 - o IF the *percent basal area conifer* is greater than or equal to the *percent basal area hardwood*,
THEN the *Composition* is **Mixed, More Pine**,
 - o OTHERWISE, the *Composition* is **Mixed, More Hdw**,
- OTHERWISE, the *Composition* is **Non-Forest**.

Variable Usage:

Description	Inventory Location	Program Code
Land cover type	Stands: ID: inventory	stand_cover_type
Conifers	Stands: ID: inventory	stand_conifer
Hardwoods	Stands: ID: inventory	stand_hardwood

Figure B-1: The forest composition rule.

Rule:

- IF there is a special case,
THEN use the *Hemel Special Case Risk*.
- IF the *Composition* is Non-Forest,
THEN use the *Anderson Wildland Risk*.
- OTHERWISE, use the *Hemel Forest Risk*.

Variable Usage:

Description	Inventory Location	Program Code
Composition	<i>Calculated (see Fig. B-1)</i>	fire_forest_comp
Hemel special case risk	<i>Calculated (see Fig. B-3)</i>	fire_special_case
Hemel forest risk	<i>Calculated (see Figs. B-4 – B-10, Table B-1)</i>	fire_hemel_risk
Anderson wildland risk	<i>Calculated (see Ch. 5; Appendix C)</i>	fire_anderson_risk

Figure B-2: The Hemel wildland fire risk assessment rule.

Rule:

- IF either *rhododendron* (*Rhododendron*) or *mountain laurel* (*Kalmia latifolia*) is present in the *ground* or *understory species* observations,
THEN the *Hemel Special Case Risk* is **Very High**.

Variable Usage:

Description	Inventory Location	Program Code
Rhododendron	<i>Plant Species Information</i>	RHODO
Mountain laurel	<i>Plant Species Information</i>	KALA
Ground species	Stands: ID: inventory: ground plots: observations	ground_spp
Understory species	Stands: ID: inventory: understory plots: observations	under_spp

Figure B-3: The Hemel special cases rule.

Rule:

- IF the *topographic position* is
'bottomland, flatland',
'upland plateau', or
'upland bottom',
THEN the *Landform* is **Valley Floor**.
- IF the *topographic position* is
'lower slope' or
'bench',
THEN the *Landform* is **Lower Slope**.
- IF the *topographic position* is
'midslope' or
'upper slope or shoulder',
THEN the *Landform* is **Upper Slope**.
- IF the *topographic position* is 'ridge top',
THEN the *Landform* is **Ridge Top**.

Variable Usage:

Description	Inventory Location	Program Code
Topographic position	Stands	stand_topo_pos

Figure B-4: The Hemel forest risk landform rule.

Rule:

- IF the stand's *aspect* is SE, S, SW, W, or NW ($135 \leq \text{aspect} \leq 315$),
THEN the *Aspect* is **South**.
- IF the stand's *aspect* is N, NE, or E ($\text{aspect} < 135$ OR $\text{aspect} > 315$),
THEN the *Aspect* is **North**.

Variable Usage:

Description	Inventory Location	Program Code
Aspect	Stands	stand_aspect

Figure B-5: The Hemel forest risk aspect rule.

Rule:

- IF the stand's *slope* is 30% or more,
THEN the *Slope* is **30+**.
- IF the stand's *slope* is less than 30%,
THEN the *Slope* is **<30**.

Variable Usage:

Description	Inventory Location	Program Code
Slope	Stands	stand_slope

Figure B-6: The Hemel forest risk slope rule.

Rule:

- IF the *Composition* is either 'Pine' or 'Mixed, More Pine',
THEN
 - o IF the *effective age* of the stand is 10 years or less,
THEN the is *Canopy Structure* is **Un-Closed**,
 - o IF the *effective age* of the stand is 60 years or more,
AND
the *canopy closure* is 50% or more,
THEN the is *Canopy Structure* is **Closed With Gaps**,
- IF the *Composition* is either 'Hardwood' or 'Mixed, More Hdw',
THEN
 - o IF the *effective age* of the stand is 5 years or less,
THEN the is *Canopy Structure* is **Un-Closed**,
 - o IF the *effective age* of the stand is 120 years or more,
AND
the *canopy closure* is 50% or more,
THEN the is *Canopy Structure* is **Closed With Gaps**,
- OTHERWISE,
IF the *canopy closure* is 50% or more,
THEN the is *Canopy Structure* is **Closed**,
- OTHERWISE, the is *Canopy Structure* is **Un-Closed**.

Variable Usage:

Description	Inventory Location	Program Code
Composition	<i>Calculated (see Fig. B-1)</i>	fire_forest_comp
Effective age	Stands: ID: inventory	stand_effect_age
Canopy closure	Stands: ID: inventory	stand_canopy_closure

Figure B-7: The Hemel forest risk canopy closure rule.

Rule:

- IF the stand's *litter depth* is 3 inches or more,
THEN the *Fine Debris* is **3+**.
- IF the stand's *litter depth* is less than 3 inches,
THEN the *Fine Debris* is **<3**.

Variable Usage:

Description	Inventory Location	Program Code
Litter depth	Stands: ID: inventory	stand_litter_depth

Figure B-8: The Hemel forest risk fine debris rule.

Rule:

- IF there is a *transect* for the stand,
AND
the minimum transect *diameter* is 3 inches or less,
THEN *Medium Debris* is **Present**.
- IF there is a *transect* for the stand,
AND
the minimum transect *diameter* is more than 3 inches,
THEN *Medium Debris* is **Not** present.

Variable Usage:

Description	Inventory Location	Program Code
Transect	Stands: ID: inventory: transects	transect
Diameter	Stands: ID: inventory: transects: observations	transect_diam

Figure B-9: The Hemel forest risk medium debris rule.

Rule:

- IF the *ground cover* is 30% or more,
 AND
 the *shrub cover* or *low slash* is 30% or more,
 AND
 the *coniferous midstory* or *high slash* is 30% more,
THEN *Ladder Fuels* are **Present**.
- OTHERWISE, *Ladder Fuels* are **Not** present.

Variable Usage:

Description	Inventory Location	Program Code
Ground cover	Stands: ID: inventory	stand_cover_ground
Shrub cover	Stands: ID: inventory	stand_cover_shrub
Low slash	Stands: ID: inventory	stand_low_slash
High slash	Stands: ID: inventory	stand_high_slash
Coniferous midstory	Stands: ID: inventory	stand_con_mid

Figure B-10: The Hemel forest risk ladder fuels rule.

Table B-1: The Hemel forest risk table.

	Composition	Landform	Aspect	Slope	Canopy Structure	Fine Debris	Medium Debris	Ladder Fuels	Risk
10	Hardwood	Valley Floor							Very Low
12	Hardwood	Lower Slope	North						Very Low
13	Hardwood	Lower Slope	South	<30					Low
14	Hardwood	Lower Slope	South	30+	Un-Closed				Low
15	Hardwood	Lower Slope	South	30+	Canopy Closure				Low
16	Hardwood	Lower Slope	South	30+	Closed With Gaps	<3			Low
17	Hardwood	Lower Slope	South	30+	Closed With Gaps	3+			Medium
19	Hardwood	Upper Slope	North						Very Low
20	Hardwood	Upper Slope	South	<30	Un-Closed	<3			Low
21	Hardwood	Upper Slope	South	<30	Un-Closed	3+			Low
22	Hardwood	Upper Slope	South	<30	Canopy Closure	<3			Low
23	Hardwood	Upper Slope	South	<30	Canopy Closure	3+			Low
24	Hardwood	Upper Slope	South	<30	Closed With Gaps	<3			Low
25	Hardwood	Upper Slope	South	<30	Closed With Gaps	3+			Low
26	Hardwood	Upper Slope	South	30+	Un-Closed	<3			Low
27	Hardwood	Upper Slope	South	30+	Un-Closed	3+			Medium
28	Hardwood	Upper Slope	South	30+	Canopy Closure	<3			Low
29	Hardwood	Upper Slope	South	30+	Canopy Closure	3+			Low
30	Hardwood	Upper Slope	South	30+	Closed With Gaps	<3			Low
31	Hardwood	Upper Slope	South	30+	Closed With Gaps	3+			Medium
33	Hardwood	Ridge Top		<30	Un-Closed	<3			Low
34	Hardwood	Ridge Top		<30	Un-Closed	3+			Medium
35	Hardwood	Ridge Top		<30	Canopy Closure	<3			Low
36	Hardwood	Ridge Top		<30	Canopy Closure	3+			Medium
37	Hardwood	Ridge Top		<30	Closed With Gaps	<3			Low
38	Hardwood	Ridge Top		<30	Closed With Gaps	3+			Medium
39	Hardwood	Ridge Top		30+	Un-Closed	<3			Medium
40	Hardwood	Ridge Top		30+	Un-Closed	3+			Medium
41	Hardwood	Ridge Top		30+	Canopy Closure	<3			Medium
42	Hardwood	Ridge Top		30+	Canopy Closure	3+			Medium
43	Hardwood	Ridge Top		30+	Closed With Gaps	<3			Medium
44	Hardwood	Ridge Top		30+	Closed With Gaps	3+			Medium
46	Pine	Valley Floor				<3			Low
47	Pine	Valley Floor				3+	Not		Low
48	Pine	Valley Floor				3+	Present		Medium
49	Pine	Valley Floor				3+	Present	Present	High
51	Pine	Lower Slope	North	<30		<3			Low
52	Pine	Lower Slope	North	<30		3+	Not		Low
53	Pine	Lower Slope	North	<30		3+	Present		Low
54	Pine	Lower Slope	North	30+		<3	Not		Low
55	Pine	Lower Slope	North	30+		3+	Not		Low
56	Pine	Lower Slope	North	30+		3+	Present	Not	Medium
57	Pine	Lower Slope	North	30+		3+	Present	Present	High
58	Pine	Lower Slope	South	<30	Un-Closed	<3	Not		Low
59	Pine	Lower Slope	South	<30	Un-Closed	<3	Present	Not	Medium
60	Pine	Lower Slope	South	<30	Un-Closed	<3	Present	Present	High
61	Pine	Lower Slope	South	<30	Un-Closed	3+	Not		Medium
62	Pine	Lower Slope	South	<30	Un-Closed	3+	Present	Not	Medium
63	Pine	Lower Slope	South	<30	Un-Closed	3+	Present	Present	High

Table B-1 (cont.): The Hemel forest risk table.

	Composition	Landform	Aspect	Slope	Canopy Structure	Fine Debris	Medium Debris	Ladder Fuels	Risk
64	Pine	Lower Slope	South	<30	Closed	<3	Not		Low
65	Pine	Lower Slope	South	<30	Closed	<3	Present	Not	Low
66	Pine	Lower Slope	South	<30	Closed	<3	Present	Present	Medium
67	Pine	Lower Slope	South	<30	Closed	3+	Not		Low
68	Pine	Lower Slope	South	<30	Closed	3+	Present	Not	Medium
69	Pine	Lower Slope	South	<30	Closed	3+	Present	Present	High
70	Pine	Lower Slope	South	<30	Closed with Gaps	<3	Not		Low
71	Pine	Lower Slope	South	<30	Closed with Gaps	<3	Present	Not	Medium
72	Pine	Lower Slope	South	<30	Closed with Gaps	<3	Present	Present	High
73	Pine	Lower Slope	South	<30	Closed with Gaps	3+	Not		Medium
74	Pine	Lower Slope	South	<30	Closed with Gaps	3+	Present	Not	Medium
75	Pine	Lower Slope	South	<30	Closed with Gaps	3+	Present	Present	High
76	Pine	Lower Slope	South	30+	Un-Closed	<3	Not		Medium
77	Pine	Lower Slope	South	30+	Un-Closed	<3	Present	Not	Medium
78	Pine	Lower Slope	South	30+	Un-Closed	<3	Present	Present	High
79	Pine	Lower Slope	South	30+	Un-Closed	3+	Not		Medium
80	Pine	Lower Slope	South	30+	Un-Closed	3+	Present	Not	Medium
81	Pine	Lower Slope	South	30+	Un-Closed	3+	Present	Present	High
82	Pine	Lower Slope	South	30+	Closed	<3	Not		Low
83	Pine	Lower Slope	South	30+	Closed	<3	Present	Not	Medium
84	Pine	Lower Slope	South	30+	Closed	<3	Present	Present	High
85	Pine	Lower Slope	South	30+	Closed	3+	Not		Medium
86	Pine	Lower Slope	South	30+	Closed	3+	Present	Not	Medium
87	Pine	Lower Slope	South	30+	Closed	3+	Present	Present	High
88	Pine	Lower Slope	South	30+	Closed with Gaps	<3	Not		Low
89	Pine	Lower Slope	South	30+	Closed with Gaps	<3	Present	Not	Medium
90	Pine	Lower Slope	South	30+	Closed with Gaps	<3	Present	Present	High
91	Pine	Lower Slope	South	30+	Closed with Gaps	3+	Not		Medium
92	Pine	Lower Slope	South	30+	Closed with Gaps	3+	Present	Not	Medium
93	Pine	Lower Slope	South	30+	Closed with Gaps	3+	Present	Present	High
94									
95	Pine	Upper Slope	North	<30		<3			Low
96	Pine	Upper Slope	North	<30		3+	Not		Low
97	Pine	Upper Slope	North	<30		3+	Present		Medium
98	Pine	Upper Slope	North	30+		<3	Not		Low
99	Pine	Upper Slope	North	30+		3+	Not		Low
100	Pine	Upper Slope	North	30+		3+	Present	Not	Medium
101	Pine	Upper Slope	North	30+		3+	Present	Present	High
102	Pine	Upper Slope	South	<30	Un-Closed	<3	Not		Medium
103	Pine	Upper Slope	South	<30	Un-Closed	<3	Present	Not	Medium
104	Pine	Upper Slope	South	<30	Un-Closed	<3	Present	Present	High
105	Pine	Upper Slope	South	<30	Un-Closed	3+	Not		Medium
106	Pine	Upper Slope	South	<30	Un-Closed	3+	Present	Not	High
107	Pine	Upper Slope	South	<30	Un-Closed	3+	Present	Present	High
108	Pine	Upper Slope	South	<30	Closed	<3	Not		Medium
109	Pine	Upper Slope	South	<30	Closed	<3	Present	Not	Medium
110	Pine	Upper Slope	South	<30	Closed	<3	Present	Present	High
111	Pine	Upper Slope	South	<30	Closed	3+	Not		Medium
112	Pine	Upper Slope	South	<30	Closed	3+	Present	Not	Medium
113	Pine	Upper Slope	South	<30	Closed	3+	Present	Present	High
114	Pine	Upper Slope	South	<30	Closed with Gaps	<3	Not		Medium
115	Pine	Upper Slope	South	<30	Closed with Gaps	<3	Present	Not	Medium
116	Pine	Upper Slope	South	<30	Closed with Gaps	<3	Present	Present	High
117	Pine	Upper Slope	South	<30	Closed with Gaps	3+	Not		Medium
118	Pine	Upper Slope	South	<30	Closed with Gaps	3+	Present	Not	High
119	Pine	Upper Slope	South	<30	Closed with Gaps	3+	Present	Present	High

Table B-1 (cont.): The Hemel forest risk table.

	Composition	Landform	Aspect	Slope	Canopy Structure	Fine Debris	Medium Debris	Ladder Fuels	Risk
120	Pine	Upper Slope	South	30+		<3	Not		Medium
121	Pine	Upper Slope	South	30+		<3	Present	Not	High
122	Pine	Upper Slope	South	30+		<3	Present	Present	Very High
123	Pine	Upper Slope	South	30+		3+	Not		Medium
124	Pine	Upper Slope	South	30+		3+	Present	Not	High
125	Pine	Upper Slope	South	30+		3+	Present	Present	Very High
127	Pine	Ridge Top		<30		<3	Not		Medium
128	Pine	Ridge Top		<30		<3	Present	Not	High
129	Pine	Ridge Top		<30		<3	Present	Present	High
130	Pine	Ridge Top		<30		3+			Very High
131	Pine	Ridge Top		30+		<3	Not		Medium
132	Pine	Ridge Top		30+		<3	Present	Not	High
133	Pine	Ridge Top		30+		<3	Present	Present	High
134	Pine	Ridge Top		30+		3+			Very High
136	Mixed More Hdw	Valley Floor							Low
138	Mixed More Hdw	Lower Slope	North						Low
139	Mixed More Hdw	Lower Slope	South	<30	Un-Closed	<3			Low
140	Mixed More Hdw	Lower Slope	South	<30	Un-Closed	3+	Not		Low
141	Mixed More Hdw	Lower Slope	South	<30	Un-Closed	3+	Present	Not	Medium
142	Mixed More Hdw	Lower Slope	South	<30	Un-Closed	3+	Present	Present	Medium
143	Mixed More Hdw	Lower Slope	South	<30	Closed	<3			Low
144	Mixed More Hdw	Lower Slope	South	<30	Closed	3+	Not		Low
145	Mixed More Hdw	Lower Slope	South	<30	Closed	3+	Present	Not	Low
146	Mixed More Hdw	Lower Slope	South	<30	Closed	3+	Present	Present	Medium
147	Mixed More Hdw	Lower Slope	South	<30	Closed with Gaps	<3			Low
148	Mixed More Hdw	Lower Slope	South	<30	Closed with Gaps	3+	Not		Low
149	Mixed More Hdw	Lower Slope	South	<30	Closed with Gaps	3+	Present	Not	Medium
150	Mixed More Hdw	Lower Slope	South	<30	Closed with Gaps	3+	Present	Present	Medium
151	Mixed More Hdw	Lower Slope	South	30+	Un-Closed	<3			Low
152	Mixed More Hdw	Lower Slope	South	30+	Un-Closed	3+	Not		Medium
153	Mixed More Hdw	Lower Slope	South	30+	Un-Closed	3+	Present	Not	Medium
154	Mixed More Hdw	Lower Slope	South	30+	Un-Closed	3+	Present	Present	Medium
155	Mixed More Hdw	Lower Slope	South	30+	Closed	<3			Low
156	Mixed More Hdw	Lower Slope	South	30+	Closed	3+	Not		Low
157	Mixed More Hdw	Lower Slope	South	30+	Closed	3+	Present	Not	Medium
158	Mixed More Hdw	Lower Slope	South	30+	Closed	3+	Present	Present	Medium
159	Mixed More Hdw	Lower Slope	South	30+	Closed with Gaps	<3			Low
160	Mixed More Hdw	Lower Slope	South	30+	Closed with Gaps	3+	Not		Low
161	Mixed More Hdw	Lower Slope	South	30+	Closed with Gaps	3+	Present	Not	Medium
162	Mixed More Hdw	Lower Slope	South	30+	Closed with Gaps	3+	Present	Present	Medium
164	Mixed More Hdw	Upper Slope	North						Low
165	Mixed More Hdw	Upper Slope	South	<30	Un-Closed	<3			Low
166	Mixed More Hdw	Upper Slope	South	<30	Un-Closed	3+	Not		Low
167	Mixed More Hdw	Upper Slope	South	<30	Un-Closed	3+	Present	Not	Low
168	Mixed More Hdw	Upper Slope	South	<30	Un-Closed	3+	Present	Present	Medium
169	Mixed More Hdw	Upper Slope	South	<30	Closed	<3			Low
170	Mixed More Hdw	Upper Slope	South	<30	Closed	3+	Not		Low
171	Mixed More Hdw	Upper Slope	South	<30	Closed	3+	Present	Not	Low
172	Mixed More Hdw	Upper Slope	South	<30	Closed	3+	Present	Present	Low
173	Mixed More Hdw	Upper Slope	South	<30	Closed with Gaps	<3			Low
174	Mixed More Hdw	Upper Slope	South	<30	Closed with Gaps	3+	Not		Low
175	Mixed More Hdw	Upper Slope	South	<30	Closed with Gaps	3+	Present	Not	Low
176	Mixed More Hdw	Upper Slope	South	<30	Closed with Gaps	3+	Present	Present	Medium

Table B-1 (cont.): The Hemel forest risk table.

	Composition	Landform	Aspect	Slope	Canopy Structure	Fine Debris	Medium Debris	Ladder Fuels	Risk
177	Mixed More Hdw	Upper Slope	South	30+	Un-Closed	<3			Low
178	Mixed More Hdw	Upper Slope	South	30+	Un-Closed	3+	Not		Low
179	Mixed More Hdw	Upper Slope	South	30+	Un-Closed	3+	Present	Not	Medium
180	Mixed More Hdw	Upper Slope	South	30+	Un-Closed	3+	Present	Present	Medium
181	Mixed More Hdw	Upper Slope	South	30+	Closed	<3			Low
182	Mixed More Hdw	Upper Slope	South	30+	Closed	3+	Not		Low
183	Mixed More Hdw	Upper Slope	South	30+	Closed	3+	Present	Not	Low
184	Mixed More Hdw	Upper Slope	South	30+	Closed	3+	Present	Present	Medium
185	Mixed More Hdw	Upper Slope	South	30+	Closed with Gaps	<3			Low
186	Mixed More Hdw	Upper Slope	South	30+	Closed with Gaps	3+	Not		Low
187	Mixed More Hdw	Upper Slope	South	30+	Closed with Gaps	3+	Present	Not	Medium
188	Mixed More Hdw	Upper Slope	South	30+	Closed with Gaps	3+	Present	Present	Medium
190	Mixed More Hdw	Ridge Top		<30		<3			Low
191	Mixed More Hdw	Ridge Top		<30		3+			Medium
192	Mixed More Hdw	Ridge Top		30+		<3			Medium
193	Mixed More Hdw	Ridge Top		30+		3+			Medium
195	Mixed More Pine	Valley Floor				<3			Low
196	Mixed More Pine	Valley Floor				3+	Not		Low
197	Mixed More Pine	Valley Floor				3+	Present		Medium
198	Mixed More Pine	Valley Floor				3+	Present	Present	Medium
200	Mixed More Pine	Lower Slope	North	<30		<3			Low
201	Mixed More Pine	Lower Slope	North	<30		3+	Not		Low
202	Mixed More Pine	Lower Slope	North	<30		3+	Present		Medium
203	Mixed More Pine	Lower Slope	North	30+		<3	Not		Low
204	Mixed More Pine	Lower Slope	North	30+		3+	Not		Low
205	Mixed More Pine	Lower Slope	North	30+		3+	Present		Medium
206	Mixed More Pine	Lower Slope	South	<30	Un-Closed	<3	Not		Low
207	Mixed More Pine	Lower Slope	South	<30	Un-Closed	<3	Present	Not	Low
208	Mixed More Pine	Lower Slope	South	<30	Un-Closed	<3	Present	Present	Medium
209	Mixed More Pine	Lower Slope	South	<30	Un-Closed	3+	Not		Low
210	Mixed More Pine	Lower Slope	South	<30	Un-Closed	3+	Present	Not	Medium
211	Mixed More Pine	Lower Slope	South	<30	Un-Closed	3+	Present	Present	Medium
212	Mixed More Pine	Lower Slope	South	<30	Closed	<3	Not		Low
213	Mixed More Pine	Lower Slope	South	<30	Closed	<3	Present	Not	Low
214	Mixed More Pine	Lower Slope	South	<30	Closed	<3	Present	Present	Low
215	Mixed More Pine	Lower Slope	South	<30	Closed	3+	Not		Low
216	Mixed More Pine	Lower Slope	South	<30	Closed	3+	Present	Not	Low
217	Mixed More Pine	Lower Slope	South	<30	Closed	3+	Present	Present	Medium
218	Mixed More Pine	Lower Slope	South	<30	Closed with Gaps	<3	Not		Low
219	Mixed More Pine	Lower Slope	South	<30	Closed with Gaps	<3	Present	Not	Low
220	Mixed More Pine	Lower Slope	South	<30	Closed with Gaps	<3	Present	Present	Medium
221	Mixed More Pine	Lower Slope	South	<30	Closed with Gaps	3+	Not		Low
222	Mixed More Pine	Lower Slope	South	<30	Closed with Gaps	3+	Present	Not	Medium
223	Mixed More Pine	Lower Slope	South	<30	Closed with Gaps	3+	Present	Present	Medium
224	Mixed More Pine	Lower Slope	South	30+	Un-Closed	<3	Not		Low
225	Mixed More Pine	Lower Slope	South	30+	Un-Closed	<3	Present	Not	Medium
226	Mixed More Pine	Lower Slope	South	30+	Un-Closed	<3	Present	Present	Medium
227	Mixed More Pine	Lower Slope	South	30+	Un-Closed	3+	Not		Low
228	Mixed More Pine	Lower Slope	South	30+	Un-Closed	3+	Present	Not	Medium
229	Mixed More Pine	Lower Slope	South	30+	Un-Closed	3+	Present	Present	Medium
230	Mixed More Pine	Lower Slope	South	30+	Closed	<3	Not		Low
231	Mixed More Pine	Lower Slope	South	30+	Closed	<3	Present	Not	Low
232	Mixed More Pine	Lower Slope	South	30+	Closed	<3	Present	Present	Medium
233	Mixed More Pine	Lower Slope	South	30+	Closed	3+	Not		Low
234	Mixed More Pine	Lower Slope	South	30+	Closed	3+	Present	Not	Low
235	Mixed More Pine	Lower Slope	South	30+	Closed	3+	Present	Present	Medium

Table B-1 (cont.): The Hemel forest risk table.

	Composition	Landform	Aspect	Slope	Canopy Structure	Fine Debris	Medium Debris	Ladder Fuels	Risk
236	Mixed More Pine	Lower Slope	South	30+	Closed with Gaps	<3	Not		Low
237	Mixed More Pine	Lower Slope	South	30+	Closed with Gaps	<3	Present	Not	Medium
238	Mixed More Pine	Lower Slope	South	30+	Closed with Gaps	<3	Present	Present	Medium
239	Mixed More Pine	Lower Slope	South	30+	Closed with Gaps	3+	Not		Low
240	Mixed More Pine	Lower Slope	South	30+	Closed with Gaps	3+	Present	Not	Medium
241	Mixed More Pine	Lower Slope	South	30+	Closed with Gaps	3+	Present	Present	Medium
243	Mixed More Pine	Upper Slope	North	<30		<3			Low
244	Mixed More Pine	Upper Slope	North	<30		3+	Not		Low
245	Mixed More Pine	Upper Slope	North	<30		3+	Present		Medium
246	Mixed More Pine	Upper Slope	North	30+		<3	Not		Low
247	Mixed More Pine	Upper Slope	North	30+		3+	Not		Low
248	Mixed More Pine	Upper Slope	North	30+		3+	Present		Medium
249	Mixed More Pine	Upper Slope	South	<30	Un-Closed	<3	Not		Low
250	Mixed More Pine	Upper Slope	South	<30	Un-Closed	<3	Present	Not	Medium
251	Mixed More Pine	Upper Slope	South	<30	Un-Closed	<3	Present	Present	Medium
252	Mixed More Pine	Upper Slope	South	<30	Un-Closed	3+	Not		Low
253	Mixed More Pine	Upper Slope	South	<30	Un-Closed	3+	Present	Not	Medium
254	Mixed More Pine	Upper Slope	South	<30	Un-Closed	3+	Present	Present	Medium
255	Mixed More Pine	Upper Slope	South	<30	Closed	<3	Not		Low
256	Mixed More Pine	Upper Slope	South	<30	Closed	<3	Present	Not	Low
257	Mixed More Pine	Upper Slope	South	<30	Closed	<3	Present	Present	Medium
258	Mixed More Pine	Upper Slope	South	<30	Closed	3+	Not		Low
259	Mixed More Pine	Upper Slope	South	<30	Closed	3+	Present	Not	Low
260	Mixed More Pine	Upper Slope	South	<30	Closed	3+	Present	Present	Medium
261	Mixed More Pine	Upper Slope	South	<30	Closed with Gaps	<3	Not		Low
262	Mixed More Pine	Upper Slope	South	<30	Closed with Gaps	<3	Present	Not	Medium
263	Mixed More Pine	Upper Slope	South	<30	Closed with Gaps	<3	Present	Present	Medium
264	Mixed More Pine	Upper Slope	South	<30	Closed with Gaps	3+	Not		Low
265	Mixed More Pine	Upper Slope	South	<30	Closed with Gaps	3+	Present	Not	Medium
266	Mixed More Pine	Upper Slope	South	<30	Closed with Gaps	3+	Present	Present	Medium
267	Mixed More Pine	Upper Slope	South	30+		<3	Not		Medium
268	Mixed More Pine	Upper Slope	South	30+		<3	Present	Not	Medium
269	Mixed More Pine	Upper Slope	South	30+		<3	Present	Present	High
270	Mixed More Pine	Upper Slope	South	30+		3+	Not		Medium
271	Mixed More Pine	Upper Slope	South	30+		3+	Present	Not	High
272	Mixed More Pine	Upper Slope	South	30+		3+	Present	Present	High
274	Mixed More Pine	Ridge Top		<30		<3	Not		Medium
275	Mixed More Pine	Ridge Top		<30		<3	Present	Not	Medium
276	Mixed More Pine	Ridge Top		<30		<3	Present	Present	High
277	Mixed More Pine	Ridge Top		<30		3+			High
278	Mixed More Pine	Ridge Top		30+		<3	Not		Medium
279	Mixed More Pine	Ridge Top		30+		<3	Present		High
280	Mixed More Pine	Ridge Top		30+		3+			High

APPENDIX C

QUICK REFERENCE GUIDE: THE ANDERSON WILDLAND RISK MODEL

Figures C-1 – C-5 offer a quick reference guide for determining Anderson’s (1982) fire behavior fuel models. Risk assessments corresponding to these fuel models can be found in Table C-1. The Anderson wildland risk model assigns qualitative wildfire risk assessments to stands. Risks are *Very Low*, *Low*, *Moderate*, *High*, or *Very High*.

Rule:

- IF the total *low slash* and *high slash* is 50% or more,
THEN use *Anderson Fuel Model 11*.
- IF the *land cover type* is forested: 'Forest', 'Broadleaf forest', 'Coniferous forest', 'Mixed Coniferous/Broadleaf forest', or 'Forested wetland',
AND
the *canopy closure* is 50% or more,
THEN
 - o IF the *Composition* is 'Hardwood' or 'Mixed, More Hdw',
THEN go to the *Anderson Hardwood Forest Model* rule,
 - o IF the *Composition* is 'Pine' or 'Mixed, More Pine',
THEN go to the *Anderson Coniferous Forest Model* rule,
- IF the *land cover type* is forested: 'Forest', 'Broadleaf forest', 'Coniferous forest', 'Mixed Coniferous/Broadleaf forest', or 'Forested wetland',
AND
the *shrub cover* is 30% or more,
THEN go to the *Anderson Shrub and Brush Model* rule.
- IF the *land cover type* is shrub or brush: 'Brush or transitional between open and forested', 'primarily shrub/brush (75% or more cover)', 'mixed herbaceous and shrub/brush', or 'Shrub and brush'
THEN go to the *Anderson Shrub and Brush Model* rule.
- OTHERWISE, go to the *Anderson Herb., Agri., Urban, Water, or Barren Model* rule.

Variable Usage:

Description	Inventory Location	Program Code
Low slash	Stands: ID: inventory	stand_low_slash
High slash	Stands: ID: inventory	stand_high_slash
Land cover type	Stands: ID: inventory	stand_cover_type
Canopy closure	Stands: ID: inventory	stand_canopy_closure
Shrub cover	Stands: ID: inventory	stand_cover_shrub
Composition	<i>Calculated (see Ch. 4; Appendix B, Fig. B-1)</i>	fire_forest_comp

Figure C-1: The Anderson fire behavior fuel model rule.

Rule:

- IF the stand is a *wetland*,
THEN use *Anderson Fuel Model 8*.
- IF the *shrub cover* is 50% or more,
THEN use *Anderson Fuel Model 6*.
- OTHERWISE,
 IF the *shrub cover* is 30% or more,
 OR
 the *height to bottom of canopy* is less than 15 feet,
 THEN use *Anderson Fuel Model sub-6*.
- OTHERWISE, use *Anderson Fuel Model 9*.

Variable Usage:

Description	Inventory Location	Program Code
Wetland	Stands: ID: inventory	stand_is_wetland
Shrub cover	Stands: ID: inventory	stand_cover_shrub
Height to bottom of canopy	Stands: ID: inventory	stand_can_bottom

Figure C-2: The Anderson hardwood forest model rule.

Rule:

- IF the stand is a *wetland*,
THEN use *Anderson Fuel Model 8*.
- IF the *shrub cover* is 50% or more,
THEN
 - o IF the *coniferous midstory* is 30% or more,
OR
the *height to bottom of canopy* is less than 15 feet above the
average shrub height,
THEN use *Anderson Fuel Model 4*.
 - o OTHERWISE, use *Anderson Fuel Model 7*.
- OTHERWISE,
IF the *shrub cover* is 30% or more,
THEN use *Anderson Fuel Model sub-7*.
- OTHERWISE, use *Anderson Fuel Model 9*.

Variable Usage:

Description	Inventory Location	Program Code
Wetland	Stands: ID: inventory	stand_is_wetland
Shrub cover	Stands: ID: inventory	stand_cover_shrub
Coniferous midstory	Stands: ID: inventory	stand_con_mid
Height to bottom of canopy	Stands: ID: inventory	stand_can_bottom
Average shrub height	Stands: ID: inventory	stand_ave_ht_shrub

Figure C-3: The Anderson coniferous forest model rule.

Rule:

- IF the *average shrub height* is 6 feet or more,
 AND
 the management unit *state* and *county* is within 50 miles of the coast,
THEN use *Anderson Fuel Model 4*.
- IF the *Composition* is 'Pine' or 'Mixed, More Pine',
THEN use *Anderson Fuel Model 7*.
- OTHERWISE, use *Anderson Fuel Model 6*.

Variable Usage:

Description	Inventory Location	Program Code
Average shrub height	Stands: ID: inventory	stand_ave_ht_shrub
State	Management unit	mu_state
County	Management unit	mu_county
Composition	<i>Calculated (see Ch. 4; Appendix B, Fig. B-1)</i>	fire_forest_comp

Figure C-4: The Anderson shrub and brush model rule.

Rule:

- IF the *land cover type* is forested: 'Forest', 'Broadleaf forest', 'Coniferous forest', 'Mixed Coniferous/Broadleaf forest', or 'Forested wetland',
THEN
 - o IF if the total *ground cover* and *litter cover* is 30% or more,
THEN use *Anderson Fuel Model 2*.
 - o OTHERWISE, use *Anderson Fuel Model sub-2*.
- IF the *land cover type* is herbaceous: 'primarily herbaceous, non woody vegetation (75% or more cover)' or 'Herbaceous',
THEN use *Anderson Fuel Model 1*.
- IF the *land cover type* is marsh: 'Wetlands (not including open water; palustrine wetlands only)', 'Emergent wetland', or 'Scrub-Shrub wetland',
THEN use *Anderson Fuel Model 3*.
- OTHERWISE, use *Anderson Fuel Model 0*.

Variable Usage:

Description	Inventory Location	Program Code
Land cover type	Stands: ID: inventory	stand_cover_type
Ground cover	Stands: ID: inventory	stand_cover_ground
Litter cover	Stands: ID: inventory	stand_litter

Figure C-5: The Anderson herbaceous, agricultural, urban, water, or barren model rule.

Table C-1: Anderson fuel models, descriptions, and risk assessments.

Fuel Model	Cover Type Description	Risk
0	Agricultural, urban, water, or barren	Very Low
1	Grassland	Moderate
sub-2	Barren open forest	Low
2	Open forest grassland	Moderate
3	Marshland grasses, Tall prairie grasses	Moderate
4	Very dense tall shrubs, Southern rough w/ ladder fuels or low canopy	Very High
5	<i>Young green shrubs (not implemented)</i>	Moderate
sub-6	Moderate density immature hardwoods	Moderate
6	Shrubs, Dense immature hardwoods	High
sub-7	Low density southern rough	Moderate
7	Southern rough	High
8	Seasonally flooded swamp	Low
9	Mature forest	Low
10	<i>Heavy down / partial slash forest (not implemented.)</i>	Moderate
11	Light slash	High
12	<i>Moderate slash (not implemented)</i>	Very High
13	<i>Heavy slash (not implemented)</i>	Very High
