Forsite, a Multiple-Project Management System:

Overview and General Description

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ABSTRACT

The Geothermal Site Development Forecasting System (FORSITE) is a computer-based multiproject monitoring, scheduling, and forecasting system. It was developed by The MITRE Corporation under contract to the U.S. Department of Energy. Its main purpose is to assist DOE geothermal program managers in monitoring the progress of multiple geothermal electric exploration and construction projects. The system actively combines conceptual project development schedules with site-specific status data to predict a time-phased sequence of development likely to occur at multiple specific geothermal sites. The forecasting capabilities of the model include estimation of industry costs and federal manpower requirements across sites on a year-by-year basis.

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1.0 INTRODUCTION

1.1 Background and Purpose

The Geothermal Site Development Forecasting System (FORSITE) is designed to track and forecast development events and requirements at specific geothermal electric prospects in the U.S. FORSITE is designed to provide Department of Energy (DOE) geothermal program managers with the ability to monitor the progress of multiple geothermal electric projects. It also enables them to anticipate staffing levels required for executing the federal actions that must take place during geothermal prospect exploration and power plant construction.⁽¹⁾

Typically, the DOE program manager, or other manager who might use FORSITE, has little or no control over the projects being monitored and only sparse data for detecting the completion of key milestones. However, he has a need to identify and influence the outcomes of major factors that affect the rate of development of some or all of the projects. To this end, he must track and understand a confusing assemblage of data of uncertain accuracy from a variety of sources. FORSITE assists in this task by correlating sparse and conflicting data with a set of generic schedules for project development and by forecasting those major events which the manager should attempt to detect.

The MITRE Corporation was asked to develop FORSITE for the Division of Geothermal Energy (DGE), DOE, because of its coordinating role in the Geothermal Progress Monitor (GPM) system, a national-level system for obtaining, analyzing, and disseminating information on geothermal energy use.⁽²⁾ This system, developed in 1979 and maintained through 1980 and 1981, is the principal source of data for FORSITE. The main challenge in designing FORSITE has been to develop activity schedules and a schedule processor which can deal with incomplete data, conflicting reports, and uncertain outcomes of ongoing activities and to match the system's data needs and data-processing capabilities to the non-proprietary data that are available about geothermal energy system development projects.

1.2 Scope

The FORSITE system is generic in nature except for one processing module and the contents of the data bases. The system could be modified easily to work with other types of projects. Certain of FORSITE's structural features were designed to allow easy adaptation to a research project management context.

The system includes as its major blocks:

- (1) Generic schedules for project developments
- (2) Hierarchical definitions of the locations of project sites
- (3) Status data about development at each monitored site
- (4) Considerations of economic factors and industrial decision rules associated with geothermal development
- (5) An executive control block that allows the user to select multiple options, data-use conditions, and calculation parameters for each run
- (6) A network formation block that configures generic development networks, and allows them to be tailored to site-specific conditions
- (7) A schedule resolver block that merges a generic network with a site-specific schedule that accurately reflects historical development at the site
- (8) A resource-requirements calculation block that compiles local, state, and national statistics on resource requirements for geothermal development, and holds them for later printing
- (9) A report-generation block that prepares most of the outputs from the system

1.3 Suggestion to the Reader

This document is intended as an introduction to the FORSITE system as a whole. It assumes the reader has general knowledge of Critical-Path-Method project scheduling systems, and some general knowledge of the geothermal industry. Section 2.0 is intended as the general introduction to the system and what it is intended to do.

2.0 SUMMARY DESCRIPTION

2.1 System Description

The chief function of the FORSITE system is to merge conceptual schedules and real status data to achieve a reasonable representation of events which have already occurred at specific geothermal prospects and events likely to occur at major prospects, including those where little real development has taken place. Thus, FORSITE functions both as an archive and as a forecasting tool. As an archive, it is a repository of historical data pertaining to major U.S. geothermal-electric sites. As a forecasting tool, it predicts, for the near-term and mid-term, the time-phased sequence of development likely to occur at a specific site. These predictions are based on the best available information about what has already happened at a given prospect and general relationships of those events to the historical patterns of development at other sites.

In its mode as forecaster, the system estimates resources (time, labor, and capital) required to support the forecasted development. Principal outputs of the system are, for specific sites, prospects, states, and the country as a whole, are: power-on-line dates, power-on-line summaries, manpower needs, and capital investment requirements.

Information generated by the system allows estimates to be made of the rate at which geothermal energy is being developed in the U.S., given the best current understanding of the advantages of and constraints to developing specific geothermal sites.

FORSITE is a tool for the program manager who has to track and influence diverse projects that are not under his direct control. It enables the manager to monitor current site-development activities and it provides a mechanism for forecasting future developments at particular prospects. Monitoring of projects over which the manager exerts close control (e.g., demonstration projects) can be maintained. But more importantly, FORSITE will give program managers an enhanced capability to detect problems that cut across a number of projects over which they have little direct control.

2.2 Key Concepts of the System

The general strategy for developing and using FORSITE for monitoring and forecasting geothermal development centers on the use of existing mechanisms (i.e., the Geothermal Progress Monitor network) to obtain the required status and forecasting information. Data are obtained on a site-specific basis and consist of reports of actual events and reports of industry's planned activities. These

data are merged, by computer, into generic development schedules which have been previously synthesized from an analysis of historical schedules for completed projects. For each project, the system then estimates major milestones and completion dates from a given start date or any major decision point thereafter.

FORSITE can also trace a schedule in reverse from a desired project completion date to required dates for all activities not already completed. When working in this mode, FORSITE reports cases where specific activities appear to have to be compressed to unreasonable degrees to meet the desired completion date. In either mode, the system makes estimates of manpower requirements and costs across sites on a year-by-year basis.

The key concept on which this strategy rests is that of time-phased activities and easily detectable industry events. Each phase, or stage of development, is a structured hierarchy, consisting of groups of activities and specific events. Each activity describes a basic unit of work or progress, contributed to by one or more organizations or entities in the private sector or in government, and terminates in a major detectable event. Activities have attributes of duration, manpower use, and cost, and are taken down to the level of permitting by individual agencies.

The last events in each phase follow from the major decisions made by industry in determining whether to continue to explore or develop a geothermal field. FORSITE system activities and events are grouped into the following six phases, each signaling a major step forward in exploring or developing a field:

- Prospect identification and delineation
- Fluid confirmation
- Production testing
- Financing
- Design and permitting
- Construction

Achievement of the last milestone (event) in each phase implies that all preceding activities in the phase have been completed and assumes certain probabilities for progressing through the next phase. It is critical that the last milestone of each phase be an easily-detectable industry event, reported in a non-proprietary manner and on a consistent basis. Most of these final milestones consist of a very early activity associated with the subsequent phase. This serves as a means of ensuring that all necessary precedent activities have been completed at least to a degree that signals a decision by the developer to progress into the next major phase of development.

This use of major detectable milestones provides a framework into which sparse data can be fitted. Even if all activities in a phase are not reported, detection of the last event of the phase gives implicit assurance that they have occurred. Accordingly, completion of any activity in a given phase implies that the preceding phase has been completed.

Because several different actions may constitute an activity group and because there may be several activity groups within each development phase, the likelihood of success in moving from phase to phase must be treated probabilistically. The likelihood estimates used in FORSITE are based on an assessment of geothermal experience in the 1970s conducted by the University of Utah Research Institute.⁽³⁾ This assessment was updated by additional recent discussions with field geologists, private developers, contractors, consultants, and government personnel.

The system also includes a mechanism which allows for "stretching" and "squeezing" of the activity durations in the generic schedule to handle either unusual constraints which would retard the pace of development or special factors that might act to speed up development.

Finally, the model is structured so that a given plant can be treated as a "springboard" for successive plants originating from different points along the schedule of the first plant. Thus the model's usefulness is increased by its ability to accommodate a second plant at a site without going through the initial stages of exploration, leasing, and certain permitting processes which in most cases would not be necessary for a second plant.

2.3 Major Components of the System

The major components of the FORSITE system are (1) generic schedules, (2) site-specific factors, (3) status data, and (4) the schedule processor.

Generic schedules, which have been derived from information based on industry experience in developing geothermal power plants, are used to predict development. The definitions of these schedules are stored in FORSITE Data Base 1. The schedules reflect the alternatives between competitive and non-competitive leasing on both Bureau of Land Management and Forest Service lands under single-stage and two-stage leasing systems. Generic schedules have also been devised for developments on private lands.

Site-specific conditions and problems that are likely to affect forecasting are entered into the system as "Prospect Definitions" in

FORSITE Data Base 2. Site-specific physical conditions, for example, will determine long-term economics and rate of development. Detection of a particular problem or barrier induces the system to stretch the generic schedule to allow for potential delays resulting from attempts to resolve such a problem.

Status data obtained for each site determine the near-term and mid-term schedule positions of geothermal developments. When related to generic schedules, status data reveal whether a development is behind, ahead of, or consistent with the forecasted schedule. These data are held in FORSITE Data Base 3, "Site Status Data."

Data Base 4 is an option built into the FORSITE system to allow for modeling alternative outcomes. It provides a set of power-on-line scenarios compiled from external estimates of geothermal power plant developments. This option can be used to drive the Decision Rules file which contains estimates of the first competitive year of a proposed power plant. This, in turn, is used by the schedule resolver.

The schedule processor is basically a critical-path-method (CPM) project management scheduling algorithm with unusual schedule and precedence override capabilities built into it. In its dominant mode of operation the processor assumes that unreported activities have been completed, provided that a subsequent major milestone has been reported as completed. Extensive data-conflict resolution algorithms are incorporated to ensure that the resulting estimates of current project status are reasonable.

One additional data base, Data Base 5, is maintained by FORSITE to keep track of all the identification codes for government agencies and private companies that are followed by the system.

2.4 Information Flow

The FORSITE system has been structured so that it operates with relatively sparse data inputs. The five principal data classes are:

- Generic schedules
- Site-specific status data
- Site-specific physical data
- Economic and decision factors
- Resource requirements

Typically, the announcement of a lease or exploratory activity identifies the generic schedule to be used in the system. As subsequent site-specific status data become available, these two data

sets are combined to estimate the development schedule for the first plant on the site.

The estimated schedule for the initial plant is then used in conjunction with status data for adjacent sites or with assumptions about step-out development in order to project development of subsequent plants. This enables FORSITE to develop forecasted schedules for all possible plants at the identified prospects.

The site-specific physical data and economic and decision factors are used in a separate small model within the system. This model projects the first power-on-line year for geothermal prospects for which power-on-line dates have not been announced by industry. It also controls the timing relationships between subsequent plants at each prospect. The forecasted schedules are then used as inputs to the resource requirement estimates, which can be reported for single plants, multiplant prospects, states, and the entire United States.

3.0 UNUSUAL FEATURES OF FORSITE

FORSITE contains a number of features that are different from those commonly found in project management software systems. The features are all targeted at handling a multiplicity of projects in the context of not being able to follow progress at those projects on a daily basis. This section emphasizes some of the most important special features of this project management system; i.e., the ability to:

- Handle multiple projects
- Work from sparse and conflicting data
- Process schedule resolutions
- Forecast future developments
- Process data in an execution-friendly manner

3.1 Handling Multiple Projects

While many project management software systems focus mainly on one project or a limited set of projects, FORSITE emphasizes an ability to deal with a multiplicity of projects that are linked together in a few different ways. In the geothermal energy version of FORSITE, the logical linkages between projects are related to and described in terms of different types of geographical areas. The names and definitions of these geographical areas reflect different types of influence of physical, managerial, and/or socio-economic conditions upon the development of specific projects.

While these areas are named "states," "prospects," and "sites" to reflect how the geothermal industry discusses a variety of influences upon energy extraction projects, the general user of FORSITE is encouraged to view the area designators in a more generic fashion.

- States are the most generic and abstract level of interaction between different projects. "States" are used to define special conditions or schedule requirements that affect a number of otherwise independent projects. The need for a special type of permit in Wyoming is a specific example. Up to 99 states may be specified.
- Prospects are groups of projects that are expected to be developed in a sequence. Each prospect is treated as a collection of "sites." The development of the sites interact in a strongly sequential manner. Many special conditions can be identified for each prospect. These special conditions are used to highlight physical and economic differences between different projects or places.

- Sites are the fundamental unit of development. Each site is a project that may succeed or fail on its own merits. The site is used as the development entity to which status data are linked to indicate real-world progress on projects.

The single most important aspect of how multiple projects are handled is the linkage between sites at the same prospect. A prospect is treated as an area which can sustain the development of a number of projects. Within each prospect, FORSITE assumes that one project will lead all others, and that later projects will be developed sequentially and affected strongly by the developmental history of the previous sites. In particular, FORSITE makes the start of each new project at a prospect dependent upon the completion of some important phase of the immediately preceding project. Establishment of this sort of linkage between projects was deemed to be necessary to reflect the common geothermal development practice of concentrating the exploration work in a new area into a single leading project, and developing power plants in a sequence as each previous plant proves more about the capacity of the geothermal reservoir.

For non-geothermal uses of FORSITE, the "states" level of classification should be viewed as sets of projects for which special groups of activities, called "hammocks," can or need to be added to the general schedule of specific projects. The "prospects" level of classification should be viewed as sets of projects which have: (a) common economic and/or physical characteristics from which development inferences must be drawn, and (b) a sequential relationship between project start times.

3.2 Working from Sparse and Conflicting Data

Most of the unusual algorithms and procedures within the FORSITE model are there to handle sparse and/or conflicting data. An on-site project manager has direct access to the activity initiation and completion data needed to support a conventional project management software system. However, the managers for whom FORSITE was developed have only limited and usually untimely access to detailed information about each project. Moreover, the available information often comes from multiple sources and frequently contains internal conflicts with respect to the apparent status of a project.

Data can also conflict with the assumed working schedule itself, since the FORSITE schedule for the project is usually a generic schedule which varies in some details from the actual project schedule. Also, the manager who is tracking projects from a distance will rarely have access to the continuously revised schedule used in

the field, even if he had started from the original planned schedule for the project.

FORSITE contains a number of features that help to ameliorate some of these difficulties.

- (1) The generic schedules used in FORSITE for the geothermal case are kept reasonably simple, so that excess detail is not demanded of the data analyst. Each schedule consists of approximately 80 to 100 activities, of which about 20 to 25 are sufficient to describe the most often reported events associated with such projects. The reader should note that the level of detail used is a matter of user "taste" which is not explicitly built into any of the FORSITE codes.
- (2) FORSITE accepts status data entries that have varying levels of user-estimated certainty or accuracy associated with them. Data with higher levels of certainty supplant and replace similar previously-entered data of lesser certainty when new data records are being entered into the Site Status Data Base (Data Base 3).
- (3) The FORSITE algorithms contain rules for arbitrating conflicts among any combination of reported start date, ongoing event date, or end date for a given activity in the schedule. This process allows inconsistent estimates to be eliminated before interactivity schedule resolution processing is begun. Emphasis is given to reported end dates for activities in estimating whether a start, end, or ongoing reported date seems to be the more reasonable.
- (4) Additional flexibility is built into the process for interpreting the relationships between the apparent actual progress at a site and a developer's announced plans for continued development. The internal rules for this resolution pay attention to the apparent actual status, the available data on announced plans, and the timing of uncompleted work as estimated in the generic schedule. These rules deal principally with the degree to which the generic durations estimated for each activity in the uncompleted portion of the schedule or network are allowed to be compressed to fit with the developer's plans.

3.3 Schedule Resolution Processing

The standard varieties of project scheduling software systems (PSSSs) use a fairly inflexible algorithm to determine the current

status of a project. In a certain sense, standard PSSSs do not have a special algorithm for this at all, since they rely on timely and accurate data from the user to pinpoint the current status and the dates of all past events for a project. However, in the managerial and data situation addressed by FORSITE, the computer code must estimate the project's current status from a set of reported dates for some but not all of the activities in the schedule.

The part of FORSITE that deals most directly with the process of estimating the project status as of a current date is called the "Schedule Resolution Processor," or SLRP. The problem addressed by this processor is to take a sparse collection of dates about project events and then estimate which project events have been completed as of any specified date.

The reader should note that any one of many algorithms could have been (or could yet be, in amended versions) chosen for this purpose in FORSITE. The only requirements for the algorithm are that it extract a present (or near-future) position from a time series of events, and that it then estimate any missing dates from earlier elements in the series. In effect, any such algorithm merely creates a mathematical mapping between the "schedule time" estimated for each event in a network that has had its critical path times worked out, and the "calendar time" estimated for each event. This mapping must be derived from the available reports of calendar dates for some or all of the events in the network.

The SLRP algorithm in the geothermal version of FORSITE is quite simple. The algorithm takes the schedule dates of events as the independent datum for a linear interpolation of calendar dates between next nearest neighbors of affected schedule dates. The schedule dates affected are all of those between the highest and the lowest schedule dates of any events (activity start dates or end dates) for which a calendar date has been reported via the records in the Site Status Data Base.

The most valuable characteristic of this algorithm is that it places credence in all reported event dates. It has the apparent disadvantage of sometimes estimating negative durations (estimated start date later than estimated end date) for activities. However, this apparent disadvantage is in fact a very useful way of allowing the SLRP algorithm to handle the real conflicts that arise when an actual schedule for activities is quite different from the generic schedule used for the project by the FORSITE system.

Such instances of apparently reversed time flow are signaled to the user in the processing report, so that they do not escape detection. However, the SLRP algorithm does not allow apparently negative

activity durations to remain in the resolved schedule. Instead, the algorithm removes such reversed dates by replacing the estimated start date of the activity with a calendar date equal to the estimated calendar end date minus one-half of the generic duration for the activity. Thus, the algorithm "unwraps" all instances of estimated negative durations and replaces all negative durations with a reasonable, positive albeit historically inaccurate duration.

3.4 Forecasting Future Developments

Once the current status for a project (one site) at a prospect has been established by the schedule resolution processor, FORSITE forecasts the calendar dates for all work estimated to be remaining for that project. FORSITE also forecasts effects of that project on other ("subsequent") projects at the same prospect. Some of the processes involved in forming these forecasts are described below. Steps related to within-site data are described first; factors related to between-site relationships are dealt with next; and then, likelihood estimates for future activities are described.

3.4.1 Within-site Processing

In its simplest forecasting mode, FORSITE dates all future activities based on the generic durations in the schedule definition, starting from the activity estimated to have been completed as of the current date. This mode is used whenever a site has been started from a reported event date or from the scheduling of a previous site, but there are no planned event data for the future of this site. In this case, FORSITE simply assumes that the generic schedule is the best prediction of what will happen at the site.

When there are data that represent industry's plans for the site, the forecasting becomes a little more complicated. Two new issues arise that must be dealt with: (1) Which of a number of planned dates is the most reasonable to accept as a target date for forecasting? (2) Given the planned date which seems to be the most useful or acceptable, is it likely that industry will accomplish as much as it claims to be able to in the time it has allotted? That is, for this second question, does it seem that the industry planned estimates for the project are overly ambitious, given FORSITE's estimate of the current status of the project and the estimates of allowable compression of activity durations contained in the network definitions in Data Base 1? (Data Base 1 contains the definitions of networks and activities.)

To select from among a multiplicity of entered planned dates, FORSITE contains a simple algorithm that searches for a planned event date that is both (a) reasonably close to the end of the project (in

"schedule" time), and (b) has a planned date that is reasonably close to the date (in "calendar" time) that the schedule durations would have projected. The first of these criteria is given roughly twice as much weight as the second by the decision metric used in selecting the date. Once the "planned date" is chosen, the other planned dates are ignored in all further processing.

Furthermore, once the "planned date" is chosen, FORSITE checks to see whether the planned duration is reasonable. The planned duration is assumed to be reasonable when the duration estimated by the industrial source for the planned activities (those between the current date and the planned date) is not significantly shorter than the amount of time estimated for those events according to the durations contained in the generic schedule. In simple terms, at this point in the processing, FORSITE checks to see whether the generic schedule can be "squeezed" to fit within the planned schedule without violating any of the "compression" factors (from Data Base 1) of the individual activities. If the operator wishes, FORSITE may be operated in a mode that "accepts all industry plans, regardless of compression conflicts," or another mode that "ignores all industry plans by forcing the generic duration upon each activity." These latter two modes are useful by way of comparison to the results that are forthcoming from the first, which is intended to be the general use mode for the model.

3.4.2 Between-sites Forecasting

Dates forecasted for a specific site at a prospect can (but do not necessarily) affect the dates forecasted for all subsequent sites at the same prospect. (Note that there is no major forecasting linkage of any sort between prospects.) The interactions that affect such intersite relationships are: reservoir capacity constraints, land acreage constraints, and a set of development sequence lag times named the "next plant decision rules."

To understand the between-sites relationships in FORSITE forecasting, it is important to know that FORSITE creates sites (power plants) at each prospect in the following sequence:

1. Historical plants--sites for which there is both an actual start date and an actual end date. For this type of plant, the "forecast" is actually a simple replication of history, as it is represented by entries in the site status data base.

2. Current plants--sites for which an actual starting date is present, but which are missing an actual end date. The end dates for these plants are estimated by the within-site rules that were described in the section immediately above.
3. Forecasted plants--plants for which neither a start date nor an end date are contained among the site status data records. It is these sites to which the between-sites forecasting rules apply.

Once FORSITE has worked through the historical and the current plants at a prospect, it predicts additional forecasted plants until either a main constraint is reached, or data suggest that development at the prospect has stopped. Any forecasted site is simply one that is being started from assumptions or rules other than status data about actual events or industry plans. A forecasted site is essentially kicked off from some milestone date estimated for the previously processed site, under a set of "next plant decision rules" or NPDRs. The NPDRs are a matrix of time lags between specified major milestones at preceding and subsequent sites. These time lags are user-selectable, and should be chosen to reflect common development or project practice in the industry being modeled.

The user should note that the first site at each prospect is unique, in that if there are no status data for it, this site is started at the current date or some later date which allows it to come on line by a power-on-line date contained in the prospect definition in Data Base 2. (Data Base 2 defines the physical and socio-economic characteristics of each prospect.) Subsequent sites (those after the first) will always be created either by status data entries or by NPDRs in relationship to the previously processed site.

The main constraints that end the process of creating new sites at each prospect are:

- Capacity: This is the usable energy contained in the reservoir, expressed in units of MWe multiplied by 30 years.
- Acreage: This is the amount of land surface available for placement of wells, expressed in units of acres. The acreage needed per power plant increases with power plant size and decreases with reservoir temperature.
- Time: Processing and reporting "calendar windows" are built into FORSITE. These windows cut off the processing or reporting of projects that would start or end outside of time frames defined by the user.

3.4.3 Likelihood of Events

One important requirement of the FORSITE model is that it produce forecasts that are reasonable with respect to the power-on-line estimates and the resources that are expected to be expended. This requirement necessitates estimating the likelihoods that various events (activities) will occur. This feature is not needed in the usual simple project management software system since each project and activity tracked by such a system is treated as certain to occur. But when multiple possible projects are monitored from a distance, and their consequences are projected into the future, allowance must be made for probable successes and failures of the projects.

FORSITE provides for such likelihood estimates by allowing a likelihood factor, which is associated with every activity in a resolved schedule, to be modified by software prior to the adding to the main reports of the resource requirements for that activity. This allows the postulated occurrence of every activity in a site schedule to be discounted with respect to the probability that it will occur. The main reason this feature is built into FORSITE is to ensure that reasonable probabilities of occurrence can be ascribed to exploration events, which have a high likelihood of failure in the real world of geothermal energy development.

In the geothermal version of FORSITE, the following four factors are assumed to affect the likelihood of any particular site coming on line:

1. Exploration--likelihood that exploration activities will result in a discovery of hot fluid of sufficient quality and quantity to support the development of the first electric power plant at a prospect.
2. Leasing--likelihood that the amount of land leased at a prospect at the time known as the "current date" is enough to ensure discovery of hot fluid, if the hot fluid is present.
3. Siting--likelihood that sites developed after the first site at a prospect will be suitable for power plant siting.
4. Capacity--likelihood that the prospect reservoir capacity is great enough to sustain the cumulative installed capacity represented by a given next site development project.

The estimates of the likelihood associated with each of these factors for any given site are based on the status of development of

the specific site and of developmental progress at preceding sites at the same prospect.

3.5 Execution-friendly Processing

Most of the FORSITE code is written in a manner that is designed to be "execution-friendly" or "unstoppable." This means only that many different types of errors are looked for by the operating computer programs that constitute FORSITE, and when errors are detected, corrections are made that tend to allow the programs to continue to operate rather than to halt the execution.

This approach is designed to ensure that most executions of the FORSITE model will tend to run to completion, while detecting a series of "errors" that the operator may elect to correct before starting the next run of the model. The most important value of this approach is that the FORSITE algorithms are thus made into fairly powerful tools for debugging errors in the data base. Moreover, the approach helps to identify why one of the programs failed at a particular point in a run.

4.0 INPUTS AND DATABASES

Much of the FORSITE model consists of information held in databases, some of which have special input handling or data checking routines associated with them. These data bases are discussed here to prepare the reader for understanding how the main data processing steps work.

4.1 Generic Schedules

The generic schedules for project (site) development are held in Data Base 1. The data that define project schedules are contained in a four-level hierarchy of specifications: networks, hammocks, activities, and resource requirements, in descending order. Consolidated activity groups for project schedules are referred to herein as "networks" until they have been submitted to critical-path processing, after which they are called "schedules."

The construction of the schedules in FORSITE emphasizes important sequential major phases of development for each project. There are six phases for the geothermal version of FORSITE, which are discussed independently of other aspects of the structure of the FORSITE generic networks. The identifying code numbers for hammocks and activities always begin with the number of the phase in which that hammock or activity will appear.

4.1.1 Networks

A "network" is the highest level of specification of a project's structure. Network specifications consist of a network name and the code numbers of all of the hammocks that make up the network. Since each hammock is constrained to lie within a single development phase, the precedence relationships of the hammocks within a network are implicit in the hammock identification numbers.

The initial FORSITE data base contains specifications of 21 different generic networks for geothermal electric development. These reflect differences in leasing and permitting procedures among various entities that control the access to geothermal resources in the United States.

4.1.2 Hammocks

Hammocks consist of groups of activities that are linked together by explicit precedence relationships. Hammocks are built into the FORSITE network definition scheme to make it easy for the operator to construct or alter complex networks from understandable simple building blocks. Each hammock consists of an identification

code number, a title, the code numbers of the activities it contains, and the precedence relationships of the activities. All the activities in a hammock lie within a single developmental phase.

The precedence relationships specified for each activity within a hammock may refer to activities of the same phase that are not present in the hammock. When the schedule is linked together, the schedule construction processor finds and establishes all designated precedence relationships among activities that have originated from all hammocks related to the same phase. This feature in the Schedule Builder allows the FORSITE user to develop complex networks by piggybacking new hammocks onto existing hammocks within a network. In those cases where the user has mistakenly specified a nonsensical relationship between hammocks, the network-building processor will assume that unspecified or uninterpretable precedents are the phase-beginning major milestone and that uninterpretable subsequents are the phase-ending major milestone. Appropriate warning messages are generated when this happens, but processing is not terminated.

4.1.3 Activities and Resource Requirements

Each activity represents the smallest unit in the work breakdown structure used to represent the project. Each activity is specified by an identification code number, a title, a duration (in decimal years), and a duration-compression factor. Each activity also has associated with it a set of resource requirements, or elements of resource, to be used in completing the activity. The specification of resource requirements is defined later.

The compression factor for an activity defines the relative degree to which this activity may be compressed in duration, or "squeezed" in time, to make a generic schedule in the model fit what appears to be going on in the real world, as reported in the site status data entries. These factors allow the user to specify how different activities can be compressed to different degrees when the model needs to squeeze a schedule. This compressibility of activity durations is one of the methods used in FORSITE to resolve conflicts between generic schedule definitions and reported event data. The allowance of different compression factors for different activities lets the user model real schedules in ways that are relatively similar to the way humans tend to react to looming deadlines.

It is also worth noting here that FORSITE provides for repeated instances of the same activity in a given hammock in a network. Activity identification codes are formatted as "nXYZ" in the activity definition part of Data Base 1, but are formatted as "nXYZ-m" in

the hammock definition part of the Data Base. This allows multiple instances of activity nXYZ to be specified in a single hammock or even group of hammocks in a network, as:

nXYZ-1, nXYZ-2, nXYZ-3, . . . , nXYZ-9

This feature is built into FORSITE to allow multiple episodes of well-drilling or other repetitive activities to be modeled in a simple manner.

Moreover, FORSITE also allows that more instances of actual occurrences of a given activity type may be inserted in the site status data base than are contained in the schedule to which those events will be correlated during execution. If there are n instances of activity A defined in a schedule, then when there are m instances of event A reported in Data Base 3 (Site Status data), with m greater than n , the first $n - 1$ instances of A from Data Base 3 will be associated with the first $n - 1$ instances of A in the schedule, while the last (m th) instance of A from Data Base 3 will be associated with the last (n th) instance of A in the schedule. If m is smaller than n , then some of the instances of A in the schedule will be treated as having no event data reported for them.

Also note that some activity numbers have special functions reserved for them. All such special numbers take the form of "n9YZ." Numbers of the form "n999" represent the successful completion of Phase n of a project. Numbers of the form "n998" represent the failure (temporary or permanent) of the project in Phase n . The processor user's manual should be consulted for details. It is important for the user to recognize that the special function endings for activity sequences allowed in FORSITE constitute a powerful lexicon of logical processing features.

Resource requirements are handled as a logical subset of each activity, and are associated with Data Base 5, Agency Definitions. This data base contains definitions and identification codes of all agencies and firms mentioned in the schedules or the site status data entries. Each activity may have multiple resource requirements and each requirement is specified by its identification code, a number of man-years, and/or a number of dollars.

In the geothermal version of FORSITE, resource requirements are not factored into any of the general processing of schedules until after the schedule has been resolved with any status data and the likelihoods of activities occurring have been estimated. Thus, among other possible features of project management software systems, levelization of resource requirements is a feature that is not built into the geothermal version of FORSITE.

4.1.4 Phases in the Geothermal Schedules

The present version of FORSITE allows six sequential phases of development to be specified and could easily be extended to nine such phases. Each phase represents a group of activities that culminate in a major milestone, at which the industry will make a major decision about whether to proceed with the project. This sequential phase structure is built into FORSITE for the following reasons:

- It reflects the sequential and uncertain, decision-laden nature of mineral resources development projects.
- It keeps the overall schedule-creation process simpler by helping the user to identify major nodes in what might ordinarily seem a confusing mass of semirelated activities.
- It makes the network and schedule processing faster, because the processing can be done over smaller and relatively uncomplicated groups of activities.

All of the Geothermal development schedules are broken into six phases, as follows:

1. Preliminary Exploration. This phase includes all pre-leasing exploration activities and describes the amount of federal and/or state work required to achieve the leasing of a parcel of land.
2. Fluid Confirmation. This phase essentially calls for the drilling of three deep wells to prove that there is hot fluid in the reservoir.
3. Reservoir Confirmation. This calls for the drilling of three more wells and extensive flow testing to accumulate sufficient data to convince a utility (generation firm) to construct a power plant on the site.
4. Financial Negotiation. This phase includes the two-way (field developer and utility), three-way (add a banker), or four-or-more-way (add some government financing agencies) negotiations that result in a signed contract for the sale of geofluid and the construction of a power plant on the site.
5. Design and Permitting. This phase consists of concurrent activities to create the final design for the power production project and to obtain all necessary economic and

environmental permits for the project (e.g., PUC Certificate of Convenience and Necessity).

6. Construction. This phase terminates in the completion of the energy system and delivery of the first power into the transmission grid.

4.2 Definitions of Locations (Data Base 2)

Data Base 2 is named the "Prospect and Sites Definition Database." The function of this data base is to define the projects that are to be processed and to steer the processors to site-specific status data that are resident in Data Base 3 (see below). The data base includes definitions of the states in which the prospects are found, and allows the creation of state-specific hammocks of activities to be appended to every project executed in the state.

The fundamental unit of this data base is the prospect, to which one or more site definitions may be subordinated. The prospect definition includes information about:

- Land ownership
- Leases already executed on federal land in the prospect
- Physical characteristics of the expected reservoir
- The generic schedule to use as default for sites
- The estimated power-on-line date based on competitive economics
- The number of sites defined for the prospect

Four different records (cards) are used to specify the information for each prospect:

1. The prospect definition card tells the processor that the prospect exists, how many site definition cards exist for the prospect, and which generic schedule will be used for the prospect as a whole.
2. A prospect long name card defines the conventional name for the prospect.
3. The physical characteristics card defines known or defaulted values for reservoir capacity, well depth, geo-fluid temperature and other major physical data for the prospect.

4. A leasing statistics card contains data which define how much acreage at the prospect is managed by the Federal Bureau of Land Management or by the Forest Service, and how much acreage is managed on a competitive basis (KGRA, or "Known Geothermal Resource Area" lands) or on a non-competitive basis (non-KGRA lands) by each of these agencies.

The "leasing statistics card" had not been envisioned as needed in the early versions of the specifications for this site development forecasting system, but was determined to be necessary as this system was defined for coding. FORSITE uses the data on this card to determine which land management agency is most likely to be responsible for leasing additional land at a geothermal prospect when the more land seems to be needed to support either exploration or power plant siting activities. The data on these cards come from statistics furnished by the U.S. Geological Survey, Conservation Division, Menlo Park, California, which has the general federal responsibility to define and monitor geothermal activities on federal leaseholds.

The "definition" cards (Type 1, above) in this data base also include "site definition" cards or records. These are single records that inform the FORSITE processor that: (1) status data exist for a particular portion (site) of this project, such data then being found in Data Base 3, and/or (2) a specific set of schedules should be used to process a site contained within the prospect. In general (but not always) there will be one site definition card in Data Base 2 for each site for which the analyst knows anything "major" about.

"Major," in the paragraph above, deserves amplification. While up to 99 site cards could be entered for each prospect, in general the geothermal version of FORSITE works with many fewer sites per prospect. It specifically does not include a site definition card for every leasehold at the site. Rather, the site definitions tend to focus on parcels that are large enough to support a commercial scale (about 50 MWe) power plant, and that seem to have had a reasonable amount of development already underway. Any early-phase initial development for a prospect as a whole is represented by the data associated in Data Bases 2 and 3 for the first site at the prospect.

4.3 Site Status Data

The data that define the planned and actual events for each site (development project) are contained in Data Base 3, "Site Status Data." There may be one or more records here for each of the

sites defined in Data Base 2. There does not have to be a record here for each site definition record in Data Base 2, since some of the site records in Data Base 2 are there only to tell the processor to use a particular schedule for that site. However, if there are one or more records for a site in Data Base 3, FORSITE will not process them unless there is a site-definition record with the same "Site Data Number" present in Data Base 2.

Each record in this data base relates uniquely to a specific site at a defined prospect and to a specific activity in the schedule used to track and forecast development at that site. For example, one record in this data base will contain all the information that is known about plans and historical events (actions) for Activity Number 1135-1 (Drill a Well) at Site (Data Number) 02 at Prospect HBER ("Heber") in State CA (California). This record might include a date at which this activity was begun and a date at which this activity is expected to be completed by the developer, as reported by the developer or as estimated by an analyst without reference to the generic schedules in FORSITE.

Besides the identification fields in each of these records, there are three event fields, and two reference fields. The event fields are associated with the "start," "activity ongoing," and "end" of the reported activity. The dates placed in the event fields will refer to either a planned event or an actual (historical or completed) event. At least one of the three event fields must have a date in it for the record to be useful to FORSITE.

The reference fields provide both the date of the latest reference from which event data were added to this record, and a reference code to the external data from which the event date estimates were obtained. A reference date is required for each record, to allow FORSITE to make inferences based on the "freshness" of the data from which it is working. A reference code (which may include alphabetic data) is not required for the FORSITE processors to work, but good bibliographic practice demands that a reference code accompany every entry into this data base.

Planned and actual events are distinguished by a "certainty level code" associated with each of the three event fields. This code also allows the assignment of varying levels of certainty to the accuracy of the reported date for actual events. A certainty level of "1" designates an event as "planned"; higher certainty levels designate an event as "actual," with the certainty of the datum increasing until the the level reaches "5."

A planned date (certainty level equal to "1") is not defined for any event of the type "ongoing activity" and will be ignored by

the processor, with an appropriate error message given. This activity type is incorporated into the system to allow the operator to enter dates for reports of the type "We know that the firm was working on this activity as of this date; but we don't know how near completion that activity was." FORSITE will infer an end date and/or a start date for that activity, given such a report, but will ignore such reports of "ongoing," when firm start and/or end dates are reported in the same record in Data Base 3.

The reader should also note that a free-standing processor, independent of the main FORSITE processor, is used to load data entries into Data Base 3. This processor, called "DB3-ENTRY," is used to create additional entries, merge information from new entries into existing records in Data Base 3 or to create new records from a new entry. It also archives the transactions that create new records or modify existing records in Data Base 3. This processor was constructed to ensure that the FORSITE user can reconstruct how data entries about a particular activity at a specific development site were combined and accumulated to result in the record of plans and events that reside in Data Base 3. The DB3-ENTRY processor also protects the user from certain quasi-fatal errors that might appear in entries to the data base.

4.4 Execution-time Control

The main processor of FORSITE is a non-interactive FORTRAN program that is controlled by the run-time parameters that are placed in specific data files prior to executing the main program. These files are described elsewhere in the documentation of the FORSITE main processor, geothermal version.⁽⁴⁾

5.0 GENERAL OPERATION OF THE SYSTEM

This section describes the overall processing flow of the FORSITE model and how the processing of separate sites is linked together with each prospect.

5.1 Hierarchical Sequence of Operations and Reports

FORSITE processes geothermal development projects in a hierarchical sequence controlled by the "Control Block Module" and driven by the sequence in which states, prospects, and sites appear in Data Base 2 (Prospects and Sites Definition). The hierarchy consists of: (1) outer loop--states, (2) middle loop--prospect in state, and (3) inner loop--sites at prospect.

Specific reports may be obtained (if selected) each time processing concludes a segment of each loop. The following list identifies and describes the various output reports.

1. Site Report. This includes the characteristics of the site and its calendar-dated (i.e., resolved) schedule are included in this report. WARNING: If this report is requested on a run where all possible sites are being processed, thousands of pages of output will be generated. This report should be called for sparingly.
2. Prospect Report. This is a one-page summary of prospect characteristics, power-on-line dates, and the amounts of generating capacity at the prospects in the state. In addition, it also includes three to five pages of resource requirements forecast for the state (disaggregated by providing agency and aggregated among prospects.)
3. Nation Report. This report includes a one-page listing of power-on-line estimates for each state and two to five pages of resource requirements forecast for the nation (disaggregated by providing agency and aggregated among states.)

The default report option for the general runs of FORSITE will provide state and nation reports (about 60 to 70 pages of output). Site and Prospect reports should be used only for debugging or data checking purposes.

A generic processing report is also available, and will be generated during each run. This report includes:

- Processing Data on Each Site--one line per state, prospect, and site that reports the main processing rules in effect for each as it was processed and certain other site schedule data useful for debugging purposes.
- Exception Reports--brief notes that explain data-and-rule interactions and are unusual, and the corrective actions that FORSITE chose in order to continue processing.

This report will consist of 10 to 50 pages, depending on the complexities of each run. It is intended as a process validation and debugging aid and will be produced on all runs to verify that processing errors occurred or did not occur.

5.2 Sequence for Each Prospect

Once it is established that projects will probably occur at a prospect, FORSITE attempts to create as many development projects as possible, subject to constraints related to:

- The estimated generation capacity of the prospect (default value = 500 MW)
- The calendar-time processing windows established for the FORSITE run (typically 1960-2000 for end dates)
- Within-project and between-project lag times inherent in the selected schedules and "Next Plant Decision Rules"
- The processing rules selected for each general run, prospect, or specific site
- The available data (from Data Base 3) about events and plans at each site

In general, FORSITE creates projects until either the end date of a project exceeds the calendar processing window for end dates for the run or the estimated electric generation capacity of the prospect has been used up by the forecasted projects.

One special provision of FORSITE ensures that all plants reported to have come on line at each prospect will show up in the output reports. A datum in Data Base 3 (Site Status Data) that reports an actual completion date for a site cannot be suppressed by specific processing rules. A basic processing rule guarantees that successful history will be reported.

A second special provision allows the operator to place a prospect or a site on hold by making an appropriate entry in Data Base 2. Placing a prospect on hold causes FORSITE to process and report only those sites that have actually come on line. A site placed on hold will not be processed.

The minimal data that will drive FORSITE to create a string of projects at a prospect is one record in Data Base 2 that defines a prospect, its generic network, and its estimated generation capacity. If no site definition records are present for the prospect, FORSITE will use the designated generic schedule to generate first and subsequent projects from the "next plant decision rules" and the "first competitive year" for the prospect.

If Data Base 2 contains definitions of sites for the prospect, those definitions will control various aspects of processing, even if there is no status data for the site in Data Base 3. When there is status data for the site, it will influence the processing for the site to the extent that the data are useful pursuant to the processing rules selected for the run of FORSITE or site-specific rules designated in Data Base 2.

A basic processing distinction is made between the first and all subsequent sites at each prospect, as described in Section 5.5.

5.3 Processing Sequence for Each Site

The processing sequence for each site is complex. This description is intended to give the user a general notion of how processing proceeds, and what various processing rules and data do to the processing stream. The processing is segregated into eight sequential steps.

Step 1: Determine if Site Should Be Processed. The following processes occur, albeit not necessarily in the listed order.

- Determination if the site (defined by the sequential processing number) is included in the prospects/sites data base
- Determination if there are status data or plan data for the site (via the linkage between Data Base 2 and Data Base 3)
- Selection of the appropriate network (from Data Base 2 or default to "Private Lease" network)

- Determination of which processing rule should be used (site-specific rule--Data Base 2--overrides a prospect-specific rule--Data Base 2--which in turn overrides the run-time general rule)
- Check of generation capacity and acreage constraints
- Determination if the site is on hold
- Determination of whether a start date can be formed from among the available data

Step 2: Get the Network for the Site. The dated generic schedule for this site is placed into the Main Schedule Buffer. This will usually be the generic schedule designated for the prospect; but site-specific schedule selection is provided for by entries in Data Base 2. If a state-specific schedule is required, this step creates that special schedule if it has not already been created during previous processing for this state. If created here, a state-specific schedule will be stored temporarily for possible use by other sites in the same state.

Step 3: Merge Status Data Into the Schedule. If the operative processing rule calls for the use of event and planned activity data for the site, the available data are retrieved from Data Base 3 and merged into the Main Schedule Buffer. Certain data-checking and data-cleaning processes occur at this step.

Step 4: Check Start and End Dates Against the Processing Calendar Windows. A site is not processed further if its current status or probable end date fall outside of date ranges defined for the current run.

Step 5: Resolve the Schedule. This process establishes a best estimate of the current status and future (forecasted) progress for the site. When there are data about actual or planned events at the site, this process is complex. It allows for missing and conflicting data. When the process is complete, a calendar date has been estimated or established for the start and end of each activity in the schedule.

Step 6: Estimate Likelihoods for Activities. Various sequential development factors are examined to estimate the likelihood that each activity in the resolved schedule will occur.

Step 7: Develop Resource Requirements and Add Them to the Report Buffers. The Report Generator Module determines what resource requirements are called for in specific years, per the resolved schedule. It accumulates these requirements in a prospect buffer, in preparation of required reports.

Step 8: Update Processing and Report-generation Control Loops. Control reverts to Module 1 to prepare appropriate reports and to proceed to the next site, prospect, or state.

5.4 Data and Processing Linkages Between Sites at the Same Prospect

FORSITE presumes that the development of one site at a prospect tends to affect the development at other sites. The general model assumed for such interactions is that one early exploration and reservoir confirmation project will lead all other developments. If the lead project is successful in bringing power on line, other successful projects are likely to follow. While some exploratory activity and establishment of mineral rights leases may occur at sites surrounding the lead project, development does not generally become intense at these sites until the lead site reaches a high degree of confirmation.

This presumption is made operational in FORSITE by:

- Generating projects in a sequential manner at each prospect
- Governing the timing relationships between successive projects at each prospect by a set of "next plant decision rules" (NPDRs)

However, there are cases where such a presumed lock-step sequence is inappropriate. The current multiutility, multifield-developer situation at The Geysers is one of these. For such cases, FORSITE contains provisions that allow projects/sites to be processed independently of each other. The main mechanism for accomplishing this is that the FORSITE operator is allowed to choose certain processing rules that are site-specific. A secondary mechanism, somewhat more cumbersome, is the possibility of breaking one prospect into two or more subsidiary prospects.

FORSITE achieves these flexibilities by including both (a) underlying linkages between successive development projects at a prospect, and (b) provisions for moderating or eliminating such linkages. Note, however, those linkages between prospects are not included in FORSITE, except insofar as they are presented to FORSITE via status and plans data entered in Data Base 3.

Processing linkages between sites have three dominant forms:

- (1) Links between site definitions in Data Base 2 and site status data in Data Base 3 via a common "site data identification code"
- (2) A process that forecasts sites in a sequential manner, based on logical rules in the program and a "site processing sequence code" resident in Data Base 2
- (3) Provisions for site-specific control codes, in Data Base 2 that fix the site processing sequential order and/or fix certain logical rules for processing sites

5.4.1 The Link between Database 2 and Database 3

Information in Data Base 2 controls the sequence in which the sites designated there will be processed. For each site designated in Data Base 2, there may or may not be status data in Data Base 3. The linkage between Data Base 2 and Data Base 3 is through a "site data identification code" assigned to site-specific data in each data base. The only function of this code is to link data. This code does not control the sequence in which sites are processed.

5.4.2 Control of Sequential Processing for Sites

As described in Section 5.2 above, FORSITE attempts to establish multiple projects at each prospect. Some of these prospects may be related to sites designated in Data Base 2. The linkage between the processor and Data Base 2 is through a "site processing sequence code" (SPSC) included for each site designation in Data Base 2. For example, if a site is labelled with SPSC = 01 in Data Base 2, that site will be processed as the first project at the prospect.

Note: The general convention is that the most advanced project at each prospect will be labeled with SPSC = 01.

5.4.3 Site-specific Control Codes

The configuration of Data Base 2 provides for a number of site-specific variations from general processing rules. These include:

- Designation of the generating capacity for the site
- Designation of a specific end-date finding rule (one of eight)

- Designation of specific first and second generic networks for the site and a calendar date on which the schedule is switched

5.5 Processing Differences between First and Later Sites at the Prospect

The main processor makes an operational distinction between the first and all subsequent projects/plants at each site. This distinction, consisting mainly of how the start and/or end dates are estimated for the project, is as follows:

- For the first site (project) at each prospect, a special process exists for estimating these dates.
- For each subsequent project, the estimated schedule dates might be affected by schedule dates from the immediately previous project.

For the first site at each prospect (SPSC = site processing sequence code = 01), the processor obeys the following sequence in attempting to establish project end and/or start dates.

- (1) If the site status data linked to SPSC = 01 show an actual completion date, this is accepted as factual, and dominates all other processing.
- (2) Next Level: If the site or prospect definition contains the designation of a specific processing rule (e.g., "Accept industry plan for completion as valid, if it exists in Data Base 3"), that rule will override the generic processing rule (e.g., "Force all planned completion dates to fit the generic schedule").
- (3) Next Level: If site-specific event or plan data exist to drive the first site to an estimated completion date, and a rule sensitive to such data is in effect, the calculated end date will be used. Otherwise, the end date is estimated from one or more rules related to the first competitive year estimate for the prospect, if one exists.
- (4) Lowest level: If none of the above conditions engender the start/end for the first plant, a plant will be started at the current date. One exception to this is possible: a processing "hold" can be placed against an entire prospect. Such a hold allows only actual completions to be processed.

For the subsequent sites at each prospect, the estimated dates for the major milestones from the previous site are retained, and estimated start and end dates can be calculated from these via the "Next Plant Decision Rules" (NPDRs). Under most processing rules, these dates will dominate the estimates of start and end dates for subsequent sites. However, site-specific processing rule designations can override the effects of the NPDRs (see Section 5.4 above).

FORSITE, then, has been designed to provide DOE geothermal program managers with the ability to monitor the progress of multiple geothermal-electric projects. It can work from sparse, conflicting, or estimated data in a manner that is "user-friendly." It also enables the program managers to anticipate staffing levels for the federal actions required to bring geothermal power plants on line.

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