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Staff Papers Series

Staff Paper P88-2

February 1988

Flow Resources, Field Time and Modeling the Farm Firm:
Concepts and Research Needs

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The comments of Iain Shuker on an earlier draft of this paper are gratefully acknowledged. Remaining errors are the responsibility of the author.

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Introduction

Farm managers make decisions in an environment of limited resources and uncertain technical and economic conditions. Allocation of fixed resources, such as land, labor and machinery, among alternative crop and livestock enterprises is a major part of the planning process. Because of the importance of time in agricultural production processes, the timing of resource use and availability is critical. In economic models of farm firms, labor and machinery should often be treated as flow resources -- resources which are measured as flows of use and availability over time. The implications of time in allocating labor and machine resources to crop enterprises is complicated by climate since the field operations which use labor and machine time can be performed only when soil and climatic conditions permit. Time during which conditions are satisfactory for field work (hereafter referred to as field time) is an essential parameter of farm decision-making. Field time information is therefore critical to managers and also to researchers involved with predicting producer behavior or prescribing economical resource use. The purpose of this paper is to discuss concepts related to the measurement of flow resources and field time for use in economic models of farm firms. Existing field time data from the Southwest Experiment Station in Lamberton, Minnesota is summarized and used to demonstrate the impacts of field time on net returns for a corn-soybean farm. Finally, alternative methods for measuring field time are discussed along with research needs.

Economic Models and Timeliness in Agricultural Production Processes

In economic analyses of agricultural production, inputs may be classified as controlled or uncontrolled inputs and as stock or flow inputs. The distinctions between these classes are important for model building. The levels of inputs such as seed, fertilizer, pesticides and machinery are controlled -- determined by the manager. The levels of inputs which are uncontrolled, such as rainfall, temperature and wind, are also important to the biological technologies of farm firms. But the levels of these inputs cannot be selected by the manager. The distinction between stock and flow resources has to do with the significance of time to the measurement of a resource's productivity and use. A stock resource is measured as a physical quantity which can be stored -- pounds of fertilizer or bushels of seed. Flow resources are measured as streams of services over time. The "best" classification of an input as a stock or a flow resource will depend upon the problem to be analyzed. For instance, machinery may be measured as a stock-- the number of machines of a particular type or the value of machinery (see papers by Peterson for examples). For many farm models in which crop and livestock enterprise selection is endogenous, however, measurement of labor and machine inputs as flows of services is desirable. When labor and machinery used in crop production are treated as flow resources, they take on characteristics of both controlled and uncontrolled inputs. Management may determine labor and machine resource allocations by hiring labor and purchasing or leasing machines and deciding how and when their services will be used. However, most crop production activities may be scheduled only when soil and weather conditions permit -- thus their use is, to a certain extent, uncontrolled.

That labor and machine inputs are sometimes best measured as flow

resources may be associated with the nature of their supply. A farm manager may gain control of the flow of services of a machine by purchasing it. Although part-time labor markets exist, the labor input is typically hired over a period of time, also. The productivity of these inputs, and thus the demand, is seasonal due to the biology of crop production. For example, for full season corn varieties, yields may be more than 15% lower on average if planted in late May rather than late April [Hicks]. Therefore, the productivity of labor and machine services used for planting depends upon the planting date. Differences in the seasonality of input demand is critical in determining optimal crop mixes. Soybean yields do not fall as dramatically with delays in planting as corn yields. And because soybeans have a shorter growing season, labor and machine services can be used for soybean planting and harvest when their productivity for corn would be low. The optimal crop mix involves an interaction of variable costs, revenues, machinery complement, labor and available field time.

When timing is considered in linear programming (LP) production activities, it is common to define discrete time periods during which resource requirements and availabilities are measured. When this is done, the analyst is implicitly assuming that within a period, flow inputs are homogeneous. While in crop production this assumption will technically seldom hold, a suitably accurate model may be constructed if time periods are sufficiently short and the activities are defined to capture the effects of timeliness. Heady and Candler discuss a criteria for defining time periods for use in flow resource constraints:

"One principle which can be used for guidance in establishing the correct number of resource categories is related to the marginal rate of factor substitution. If the marginal rate of substitution between, say, labor of

two possible periods is constant and equal to 1 for all activities, then the two labor periods can certainly be aggregated into a single restriction." [p. 208]

Strictly speaking, the expected productivity of labor and machine services for planting corn changes daily during the planting season. The length of planting periods for a particular model and application is a practical concern to the model builder. While timeliness effects are more accurately captured when more and shorter periods are defined, doing so may increase model building costs and/or exceed the limits of available data.

While the concept of field time is directly related to crop production operations, it suggests important issues for modeling livestock production, also. For many livestock production systems, uncontrolled variables such as weather have little effect on the availability of flow resources. However, the opportunity cost of labor or machine services allocated to livestock activities is influenced by the demand for the inputs by crop activities and thus the suitability of conditions for field work. Therefore, in modeling livestock production, it may be desirable to distinguish between resource requirements for livestock production operations which must occur at particular times and those which may be delayed. For example, feeding operations must be completed even though conditions may be satisfactory for field work. However other operations, such as waste handling, could possibly be delayed until field work has been completed or is not possible. One way to capture flow resource availability in a mathematical programming model when livestock production activities are included is to have both field time and total time constraints. The resource requirements on livestock production activities would differ between the two sets of constraints. In a field time constraint, the resource requirement would be that for operations which must

occur at scheduled times (such as feeding) multiplied by the ratio of field time to total time in the period.¹ The total livestock resource requirement would be used in the total time constraint for the corresponding production period. For crop production activities, resource requirements would be the same in the two constraint sets.

Economic models of farm firms often include some measure of available field time in flow resource constraints. However, descriptions of such models which appear in the literature seldom include detail about the measurement of field time. A few exceptions will be discussed here. Baker and McCarl studied how aggregation of time in resource constraints influences solutions to programming models of midwestern corn-soybean farms. Building on the criteria suggested by Heady and Candler, they investigated the sensitivity of LP farm models to changes in parameter values given various levels of time aggregation in the flow resource constraints. By parametrically altering the risk coefficient in a MOTAD model, Baker and McCarl demonstrated that realistically diversified crop mixes, explained only by risk aversion in highly time-aggregated models, are optimal even for profit maximizing firms when timeliness effects are captured. While Baker and McCarl do not recommend a specific number of production periods to use in a model, they effectively demonstrate that serious errors may result when too few periods are included.

Several examples appear in the literature of the treatment of field time as a stochastic variable in economic models. An application of chance constrained programming was used by Boisvert and Jensen for a farm planning problem in which field time was stochastic. Danok, McCarl and White analyze optimal machinery selection using a combination of mathematical programming

¹ The ratio of field time to total time for the period might be interpreted as the proportion of the resource use which will unavoidably occur when field operations are possible.

and stochastic dominance. They use cumulative probability distributions of field time based upon 18 years of observations for each period in a 22 period model. A mixed integer programming model is used to find optimal machinery complements with field days set at levels associated with various probabilities. The authors point out that their analysis assumes perfect correlation of field time levels across all time periods. This issue is a critical one in evaluating field time as a source of risk. Pfeiffer and Peterson also used cumulative probability distributions of field time in an analysis of machinery selection in the Red River Valley. They found least cost machine sets for farms of given size and given probabilities of "timely performance of field operations." Field time measurement in this study was based upon simulation models driven by weather variables.

The models used in Apland, McCarl and Baker and in Kaiser used discrete states of nature to represent field time variability. Apland, McCarl and Baker used a discrete stochastic sequential programming model to analyze the variability of crop residue supply. Two decision stages were used with field time treated deterministically in the planting stage and stochastically in the harvest stage. To define fall field time states of nature, 15 years of observations were split into five groups according to total fall field time. Total fall field time was averaged for each group, then allocated among harvest stage production periods based upon the proportions of a representative observation. Kaiser's model was structured similarly, but used 10 observations directly as the fall field time states of nature. Both approaches capture, to a certain extent, the variability of field time, and also the covariability across production periods.

Fletcher and Featherstone's study of tillage system economics introduces an interesting twist to the field time question. They note that management

practices, specifically the tillage system used, influence the rate at which soil will dry and thus the amount of available field time. They use a linear programming model to analyze returns under conventional and conservation tillage systems. In their model, the flow resource constraints were influenced by the tillage system in two ways -- the resource requirements were different as a result of differences in field rates for the tillage and planting operations, and available labor and machine time differed because of the tillage system's effects on field time.²

Field Time Variability and Income Variability

To demonstrate the effects that available field time has on farm profitability, a linear programming (LP) model of a Southern Minnesota crop farm was constructed. Observations of field time from the Agricultural Experiment Station at Lamberton, Minnesota were used for the 1974 through 1983 crop years [Kaiser]. Field time was measured in days. For each day, a 0, 0.5 or 1 was recorded indicating (approximately) the proportion of the day during which conditions were satisfactory for performing field operations. Eleven production periods were defined for production activities and resource constraints. Table 1 shows the calendar dates for these production periods and the number of field days in each period and year. The 10 year mean field days and standard deviations by period are also given. The same data are reported in Table 2 as percentages of the number of days in each period. Variable cost, yield, resource requirement, and field time parameters used in

² A third important impact of tillage systems, related to timeliness and flow resource productivity, involves the effect of tillage on the relationship between yield and planting date. Surface crop residues slow the warming of soils in the spring. Since tillage systems vary with respect to the amount of residue left on the soil, the relationship of planting date to yield varies across tillage systems [Gupta].

Table 1: Observed Field Days, Lamberton Minnesota, 1974-1983.

		Observed Field Days by Year												Std
Period	Days	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	Mean	Dev	
1 07-Apr 22-Apr	16	6	0	12.5	2	0	0	2	7	0	0	2.95	4.03	
2 23-Apr 01-May	9	7	0	5	7	1	0	9	3	5	1	3.80	3.09	
3 02-May 11-May	10	6	8	10	6	7	2.5	8	6	4	3	6.05	2.24	
4 12-May 21-May	10	0	6	9.5	5	8.5	9	5	8	0	6	5.70	3.23	
5 22-May 31-May	10	0	7	8	2	6.5	5.5	5	6	3	7	5.00	2.42	
6 01-Jun 08-Jun	8	0	5	8	7	3	5.5	0	4	4	5	4.15	2.49	
7 15-Sep 30-Sep	16	16	11	10.5	7	11	16	10	12	9	8	11.05	2.85	
8 01-Oct 16-Oct	16	11.5	15	15	7	13	11.5	14	5	1	8	10.10	4.45	
9 17-Oct 31-Oct	15	12	14	11.5	14	15	7	8	12	12	12	11.75	2.40	
10 01-Nov 15-Nov	15	9	10	15	10	13	11	13	15	6	10	11.20	2.68	
11 16-Nov 30-Nov	15	5	3	0	3	0	5	14	3	0	1	3.40	3.98	
Total	140	73	79	105	70	78	73	88	81	44	61	75.15		

Table 2: Observed Field Days as Percent of Total, Lamberton Minnesota, 1974-1983.

————— Observed Field Days as Percent of Total —————														Std
———— Period ———	Days	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	Mean	Dev	
1 07-Apr 22-Apr	16	37.5	0	78.1	12.5	0	0	12.5	43.7	0	0	18.4	25.2	
2 23-Apr 01-May	9	77.8	0	55.5	77.7	11.1	0	100	33.3	55.5	11.1	42.2	34.4	
3 02-May 11-May	10	60	80	100	60	70	25	80	60	40	30	60.5	22.4	
4 12-May 21-May	10	0	60	95	50	85	90	50	80	0	60	57.0	32.3	
5 22-May 31-May	10	0	70	80	20	65	55	50	60	30	70	50.0	24.2	
6 01-Jun 08-Jun	8	0	62.5	100	87.5	37.5	68.7	0	50	50	62.5	51.9	31.1	
7 15-Sep 30-Sep	16	100	68.7	65.6	43.7	68.7	100	62.5	75	56.2	50	69.1	17.8	
8 01-Oct 16-Oct	16	71.9	93.7	93.7	43.7	81.2	71.8	87.5	31.2	6.3	50	63.1	27.8	
9 17-Oct 31-Oct	15	80	93.3	76.6	93.3	100	46.6	53.3	80	80	80	78.3	16.0	
10 01-Nov 15-Nov	15	60	66.6	100	66.6	86.6	73.3	86.6	100	40	66.6	74.7	17.8	
11 16-Nov 30-Nov	15	33.3	20	0	20	0	33.3	93.3	20	0	6.7	22.7	26.5	
Total -----	140	51.8	56.4	75.0	50.0	55.7	52.1	62.9	57.9	31.4	43.6	53.7		

the model were derived from those used by Kaiser. The ROMP-FS1 matrix generator and report writer were used to construct the model and report the solutions [Apland]. Details of the model structure are given in the appendix along with a listing of the ROMP-FS1 input file.

For simplicity, the production problem was modeled deterministically. It was implicitly assumed that the decision-maker knew all problem parameters including prices, yields and available field time when production activities were selected. Modeling the problem in this way ignores the impacts of field time risk and the sequential nature of farm resource allocation problems. However, by solving the model with each of a set of observations on field time, it was possible to provide a conservative estimate of the effect of field time on profitability using readily available data.³ Eleven runs of the LP model were made, each with different levels of available field time. In the first run (the "Base Run"), the mean levels of field time in each period were used. Then a solution was generated with each of the 10 field time observations used in the resource constraints (see Table 1). Optimal solutions for the eleven model runs are reported in Table 3.

When field days were set to observed levels, net revenue ranged from \$105,995 with the 1982 observations to \$117,423 when the 1974 observations were used. Mean net revenue over the 10 runs with observed field days was \$112,902 and the standard deviation was \$4,312. When the 10 year means were used for field days in each period, net revenue was \$117,274 -- for 8 out the 10 runs using observed field days, net revenue was below this level. Significant adjustments in crop mix are evident across model runs. Corn production ranged from 135.8 to 306 acres. Averaged over the 10 observations, the crop

³ Data needs for the analysis of field time risk are discussed later in the paper.

Table 3: Summary of Solutions to the Linear Programming Model.

Field Days Observation	— Crop Mix, Acres —		Total Acres	Net Revenue	Deviation from Base Net Revenue
	Corn	Soybeans			
1974	306.0	306.0	612	\$117,423	149
1975	287.2	324.7	612	110,535	-6738
1976	306.0	306.0	612	117,407	133
1977	306.0	306.0	612	116,288	-986
1978	287.2	324.7	612	111,527	-5747
1979	135.8	476.2	612	108,843	-8431
1980	306.0	306.0	612	117,148	-125
1981	257.7	354.3	612	116,516	-758
1982	275.3	295.2	571	105,995	-11278
1983	217.3	394.7	612	107,339	-9934
Means	268.5	339.4	608	\$112,902	
Standard Deviation of Net Revenue				\$ 4,312	
Minimum Net Revenue				\$105,995	
Maximum Net Revenue				\$117,423	
Base Case	290.2	321.7	612	\$117,274	

mix included about 268.5 acres of corn and 339.4 acres of soybeans. If mean field days were used in each period, the optimal crop mix included 290.3 acres of corn and 321.7 acres of soybeans. Because the base case results for net revenue and crop mix are close to the extremes for the runs with observed field days, it appears that the use of mean field time levels distorts flow resource availability. While the results of this simple analysis are not conclusive in this regard, the use of mean field time levels as representative of the flow resource endowments should be questioned. The results also suggest that field time variability may contribute significantly to risk.

Measuring Field Time and Field Time Research Needs

There are a variety of potential sources of data for measuring field time. Direct observations of time suitable for field work may be made.⁴ Because of climatic and soil differences, such observations will be most representative of a range of specific farm conditions if kept for a variety of locations and soil types. Simulation models may be used to generate estimates of field time for locations at which no direct observations have been made. For locations where field time data have been collected, simulation may be used to estimate field time in years or periods during which no direct observations were made.

While specific details vary widely, two general approaches to the simulation of field time may be found in recent literature on the topic. In areas where the availability of direct observations is limited, simulation of field time using soil moisture budgeting techniques is common [Hetz, Gold and Reese; Bolton, Penn, Cooke and Heagler; Selirio and Brown; Baier]. With this approach, moisture levels in various soil strata are simulated using climatic

⁴ Examples are reported here in Table 1 and in Fulton, Ayres and Heady.

data and soil moisture budgeting techniques. The suitability of conditions for field work is then defined with respect to the soil moisture attributes (see Figure 1). As noted before, simulation may be used when no field time data exist, but may also be used to extend historical time series of observations. In the later case, direct observations may be used to validate the simulation model used to estimate field time in other years or at other locations as in the study by Bolton, et al.

A second approach to field time simulation was used by Boisvert and Jensen. They used 7 years of observations of field time from Lamberton Minnesota to estimate parameters of a regression equation. Field days as a percent of days in a production period was the dependent variable. Rainfall and temperature were explanatory variables. 59 years of rainfall and temperature data were then used to estimate a time series of field days. Referring to the simulation model illustrated in Figure 1, the approach used by Boisvert and Jensen in essence captures both the soil moisture and machine performance subsystems in the estimated regression model. This approach proved useful to their study in providing an extended time series of field time data for a specific location. In principle, though, the soil moisture budgeting technique appears to be more flexible in that the potential exists for altering specific parameters of the subsystems of the model. The soil moisture subsystem could be modified to adapt the model to different locations and tillage practices. Similarly, the machine performance subsystem could be modified to reflect the various conditions necessary for specific types of field operations. By design, a simulation model with soil moisture budgeting and machine performance subsystems is adaptable to modeling field time under changing weather patterns and machine technologies, also.

A critical element in improving economic models of Minnesota farms in-

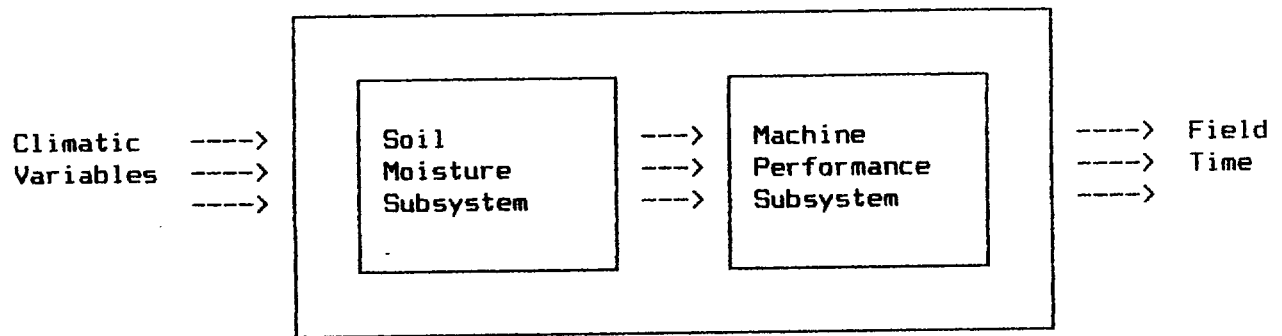


Figure 1: General Illustration of a Simulation Model for Estimating Field Time.

volves developing appropriate field time measures and modeling techniques for flow resource constraints. Research in the area of field time measurement should focus especially upon needs related to economics issues of current importance. However, it is also essential that databases be maintained to support timely research of new farm problems as they arise. Three areas of emphasis for field time research might be identified. They include: 1) measurement of field time, 2) ways of representing field time availability in the flow resource constraints of economic models, and 3) field time data systems.

Existing time series of field time data at various locations in Minnesota (such as the Lamberton data) should be compiled and analyzed. Where gaps exist in the data, collection of data at other sites should be considered. For regions and soil types which are not adequately represented by existing data, simulation models should be developed to extend the measurement of field time. Data and simulation techniques should allow for the stochastic nature of field time to be captured. Estimates of probability distributions of field time by production period should be supported by available data and simulation techniques.⁵ The measurement of covariabilities across production periods should be supported, also.

Farm resource allocation problems are inextricably linked to dynamic aspects of crop production involving timeliness of production practices and flow resource availability. A challenge to economists will involve the development of techniques to adequately represent field time availability in models of farm firms. Depending upon the class of problems, this will involve determining acceptable trade-offs between model complexity and accuracy. Such

⁵ Production periods in a farm model are defined differently depending upon the type of farm and the analysis being performed [Baker and McCarl]. Field time data and estimating techniques should be flexible in this regard.

trade-offs are especially apparent when the random nature of field time is addressed. To capture timeliness aspects of farm resource allocation problems, it will be necessary also to research the yield response of inputs as the timing of production practices vary. Research into problems such as how yields are effected by planting date under various tillage systems should focus on both average yields as well as yield variability.

Finally, development of field time database management systems would greatly enhance farm firm model building capabilities. These systems should support the storage, retrieval and analysis of the potentially sizeable field time observations as well as climatic data associated with field time simulation models. Corresponding to the data and modeling issues discussed above, field time data systems should allow the model builder to retrieve data for a variety of locations, soil types and management practices. Such a system would facilitate the development of field time measures which are problem specific and flexible for a range of applications.

Summary

Because of the unique dynamics of the biological technologies of agriculture, the timing of resource use and availability is critical. In economic models of farm firms, labor and machinery should often be treated as flow resources -- resources which are measured as flows of use and availability over time. This is especially true for models in which crop and livestock enterprise selection is endogenous. Measurement of available field time is a necessary component of defining flow resource constraints. Therefore, field time estimates are important to managers and to researchers involved with predicting producer behavior or prescribing economical resource use. Because of the effects of climate on field time, the availability of flow resources

such as labor and machine services is stochastic -- a characteristic often ignored in models of the farm firm. Conservative estimates of the effect of field time variability on farm income variability suggest that field time is an important source of risk to farmers.

Further research pertaining to field time and timeliness of input use will allow analysts to build more reliable firm models. Future research should focus on the collection, management and analysis of field time data, methods for including flow resource constraints in economic models of the firm, and systems for the storage, retrieval and manipulation of field time information.

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Appendix

The linear programming model was constructed using the ROMP-FS1 software [Apland]. The model was of a 612 acre corn-soybean farm in Southern Minnesota. Crop production activities for continuous corn, continuous soybeans, and corn and soybeans in rotation were included in the model. Eleven production periods were defined for production activities and resource constraints, as indicated in Table A.1 which shows the timing of field operations included in the model. Production operations included plowing, disking, herbicide application, planting, cultivation and harvest. Resource constraints included full time and part time labor by period; tractor, tillage equipment, planter, combine and grain drier time by period; and land. The objective function was expected net revenue, which was maximized. The input data file for ROMP-FS1 is listed in Table A.2.

Available labor and machine time in a period (the righthand sides of the labor and machine constraints) were calculated as follows:

$$\text{Available Field Days} \times \text{Hours Per Day} \times \text{Number of Units}$$

where the number of units was the number of workers or the number of machines. Eleven solutions were generated. For the first run, available field days was set at the mean for each period. Then a solution was found using each of the ten sets of field days observations.

Table A.1: Calendar of Field Operations.

Period	Tillage Operations			Planting		Harvest	
	Plow	Disk 1	Disk 2*	Corn	Soybeans	Corn	Soybeans
1 07-Apr 22-Apr	X	X					
2 23-Apr 01-May	X	X	X	X			
3 02-May 11-May	X	X	X	X	X		
4 12-May 21-May		X	X	X	X		
5 22-May 31-May		X	X	X	X		
6 01-Jun 08-Jun		X	X		X		
7 15-Sep 30-Sep	X						X
8 01-Oct 16-Oct	X					X	X
9 17-Oct 31-Oct	X					X	X
10 01-Nov 15-Nov	X					X	
11 16-Nov 30-Nov	X						

* Concurrent with planting.

Table A.2: Input Data for ROMP-FS1.

[illegible]

Table A.2: Input Data for ROMP-FS1, Continued.

201	2.25	2.45	114	32.6	105	9999						
202	2.25	2.45	114	32.6		9999						
203	6.00	6.25	58.7	16.9	38.6	9999						
204	6.00	6.25	58.7	16.9		9999						
221	7.63	1.1	0	0	0	0	0	0	2.6	2.1	1.05	
222	7.63	1.1	0	0	0	0	0	0	2.6	2.1	1.05	
223	7.63	1.1	0	0	0	0	0	0	3.1	2.1	1.05	
224	7.63	1.1	0	0	0	0	0	0	3.1	2.1	1.05	
241	17	9999	22	27	32	9999	9999	9999	0	0	0	
242	17	9999	22	27	32	9999	9999	9999	0	0	0	
243	13	9999	23	33	43	9999	9999	9999	0	0	0	
244	13	9999	23	33	43	9999	9999	9999	0	0	0	
281	6.72	4.07	1.1	10.2	1.1	11.6	1.1	0	0	0	0	
300	20000											
305	6.5	0.0	0.0									
2000	1	2										
2001	1.021	.976	.895	.802								
2002	1.000	.956	.875	.785								
2003	.980	.937	.859	.769								
2021	24	26	29	27								
2022	18	20	21.5	16								
2023	15.5	16.8	17.8	15.5								
2040	3	4										
2041	1.000	.961	.914	.872								
2042	.950	.905	.870	.827								
2043	.820	.789	.752	.714								
2061	13	13	13	13								
2062	13	13	13	13								
2063	13	13	13	13								