MATHEMATICAL PROGRAMMING FOR RESOURCE POLICY APPRAISAL UNDER
MULTIPLE OBJECTIVES

By

Bruce A. McCarl

Working Paper #6, 28 pages, November, 1992

For more information, contact:

Bruce A. McCarl
Professor of Agricultural Economics
Texas A&M University
College Station, TX 77843   USA

Tel: (409) 845-1706
Fax: (409) 845-6378

* Some figures and/or tables included in the printed version of
this publication could not be included in this electronic
version.  If you need copies of these figures or tables, please
contact the author.


PROJECT INFORMATION

A USAID-funded global program, the Environmental and Natural

ABSTRACT

Mathematical programming is one technique that can be used for

resource policy appraisal.  Multiple objectives are usually
involved in resource policy considerations.  This paper discusses
issues regarding the use of mathematical programming techniques
for the multiobjective resource policy arena.  Theoretical models
are introduced with a separation called for between producer
response models and policy maker models due to a disparity of
objectives.  The paper draws on the literature citing cases where
producer level models have been utilized to simulate the policy
outcome implications of alternative policies.

CONTENTS

MATHEMATICAL PROGRAMMING FOR RESOURCE POLICY APPRAISAL
UNDER MULTIPLE OBJECTIVES

When I was contacted about this paper, I was informed that several contexts were relevant.  These are:

* Narrowing the topic from operations research to mathematical programming

* Modeling and support of environmental policy decision making

* Relevance to international development

* Inclusion of case studies

Consequently, this paper will overview multiple-objective mathematical programming as it has been and could be applied to environmental policy actions, largely from an international development context.  I also should indicate that my Agricultural Economics background will bias the presentation toward agriculture and that the time available for construction of this paper led me to draw most of the references and case studies from my own work.


Why Examine Such a Topic?


Mathematical programming deals with the selection of decision variable values so as to maximize an objective (or set of objectives) subject to constraints.  Why is such a technique relevant to Environmental and Natural Resource Policy and Training (EPAT) activities regarding resource policy in an international development setting?  There are actually two contexts in which such an approach makes sense.

1. The selection by policy makers among a set of alternative environmentally related actions.

2. Producer reactions to environmentally-related policy actions.


First, let us examine the policy maker question.  Policy makers potentially have many actions they may undertake.  Consider policy toward soil erosion reduction.  Policies could be implemented which:

* Subsidize particular kinds of soil management practices or related equipment.

* Promote educational programs disseminating information on the benefits of conservation tillage.

* Adopt a regulatory approach where certain practices are prohibited.

* Subsidize farmers so severely erodible lands are treated with

erosion control practices.

These alternatives constitute a variety of potential decisions (variables).  Agency work force and budget plus numerous other factors would constrain choice among these variables.  Thus, the mathematical programming structure is present.  Multiple objectives would also be relevant in that policy makers might be concerned with such things as:

a) government budget exposure;

b) income of target groups;

c) agricultural production;

d) export levels;

e) consumer prices;

f) quantity of soil conserved;

g) damages due to soil erosion; and

h) water quality.

The second modeling question involves forecasting producer reactions to environmental policies.  In the soil conservation example, farmers can employ a number of choices in responding to an erosion program.  Alternative tillage and residue management practices, crop mix, multiple cropping, and rotations could be used.  Changes in farming practices may entail different hired labor requirements.  The family diet may also change in response.

Thus, a producer model could have tillage, cropping, rotation, hired labor and diet formulation variables.  Constraints would involve land, family and hired labor, machinery, draft animals, family dietary requirements, crop rotations, and multiple cropping possibilities.  Again, the mathematical programming structure is present.  The multiple objective context is relevant from both the farmer and policy maker perspectives.  The farmer could be interested in income, risk exposure, subsistence behavior, labor-leisure tradeoffs, and hired labor acceptance. Objectives for other family members could be relevant where culturally driven division of effort is important. Simultaneously policy makers might be interested in the way  soil erosion rates, farm income, government cost, off farm sales, and employment are affected by farmer reactions.

Why use Mathematical Programming Particularly for Response Forecasts?

A fair question in the context of this paper is why use a programming-based methodology rather than an extrapolative (econometric or statistical) approach or a simulation model.

This is a question without a definite answer.  The salient
characteristic of a mathematical program in this regard is that
it constructs a synthetic representation of supply response based
on an assumed objective and sets of variables and constraints.
As such then considerations in using alternative models are as
follows:

1. Is it reasonable to think that the actions motivated by the
environmental change can be extrapolated from historical behavior
and is enough data present to specify the relationships from
which to extrapolate? (If so, do so.)

2. Is there sufficient reason to believe there are enough
possible solutions in interaction with the constraints that the
range of possible solutions requires one to model goal seeking
behavior rather than relying on process following simulation?
(If not, consider simulating.)

3. Are the time, financial, personnel, data and other resources
available in adequate quantity?


This paper will proceed assuming mathematical programming is the
chosen method.


TOWARD A FORMAL STATEMENT OF MODELS


The programming models discussed above can be expressed formally.


Policy Model


Suppose the policy maker has the decision sets S for subsidies, T
for taxes, and R for regulations while being interested in the
outcome set Ob.  Further, suppose that F2(S,T, R) predicts the
outcome set implications of the policy instruments and F1(S,T,R)
reflects usage of a set of  policy constraining resources which
limit policy actions.  Formally a model of this can be written as
follows:

In this model, the policy maker chooses values for S,T, and R
while Ob gives the resultant objective.

In this model, the policy maker  chooses values for S,T, and R
while Ob gives the resultant objective levels and V(Ob) reflects
the policy objective function.  The first constraint contains the
term F1(S,T,R) giving the budgetary and other limited resource
implications of selecting various actions, while b1 gives
resource endowments.  Simultaneously, F2(S,T,R) gives the outcome
set implications of alternative policies and these are

accumulated into the outcome measures (Ob).

This is a multiple objective programming problem requiring identification of a number of items.

1. The relevant policy decision variables are the members of the sets S,T,R.

2. The relevant objectives are the members of the set Ob. In general Ob contains a number of policy relevant outcomes. Such objectives may include diverse outcomes such as soil lost, pounds of pesticides used, carbon emissions, government subsidy costs, farm employment and earnings by small farmers.

3. The function V(Ob) values the outcomes. This is an explicit statement of government, policy maker and or donor agency preferences for the policy relevant outcomes. Some outcomes may be desirable and others may be undesirable. This function is anticipated to be nonlinear exhibiting decreasing marginal satisfaction from increasing amounts of the outcome. Specification of the function may involve a number of the techniques from multi-objective programming including elicitation (Barnett, Blake and McCarl 1982), revealed preference estimation (Brink and McCarl 1978, Weins 1976), pareto extreme point generation (Steuer 1978), decisionmaker interaction (Candler and Boeljhe 1977) or assumption/sensitivity analysis (Brandao, McCarl and Schuh 1984). Romero further discusses these issues. However, we should note that none of these approaches have been meaningfully applied to specifying V(Ob) for the policy maker problem.

4. The implications of the policy instruments for the objective outcomes is expressed in the functions F2(S,T,R).

5. The constraints which limit policy give the dimension of the first constraint set and the endowments of the resources involved are in b1.

6. The usage of the policy constraint resources by the policy instruments are in the functions F1(S,T,R).

Meeting requirements 3, 5 and 6 pose difficult data development tasks, while meeting requirement 4 in general is nearly impossible.

This particular model, if it could be specified (and it really never has been) would help policy makers choose the exact policies to utilize so that they maximize some particular objective. This is a normative or prescriptive policy model.


Producer Response Modeling


Suppose producers have a set of production choices X, care about a general set of outcomes (W) and income (I), operate in a

setting where government can subsidize, tax, and/or regulate
them.  Suppose S, T and R define government actions in these
three areas.  A formal statement of the producer response problem
is as follows:

Here resource constraints limit production response--H(X) is less
than or equal to N(R), but the resource endowment is influenced
by regulations--N(R).  Farm income (I) involves farm activity as
well as subsidies and taxes--K(X,S,T).  Realization of the other
farm objectives (W) is a function of farm activity --M(X).
G(W,I) reflects the producers valuation of multiple objectives
and is setup using the same procedures discussed when defining
the V(Ob) function above.

Accounting for policy-maker objectives is also included in the
term Q(X). Thus, the model depicts producer choices which are
influenced by taxes, subsidies and regulations.  This model is a
predictive model usually used in scenario analyses to examine the
producer reactions to changes in policy.  This model therefore
generates some of the information that would be used in the first
model,and the two models conceptually can be unified as discussed
below.

A Unified Policy Maker, Policy Reactions Model

Examine the two models above.  The first one chooses policy but
needs predictions of the policy objective implications of
producer reactions.  The second starts with knowledge of the
policies and generates predictions of producer reactions.  This
distinction is important as when policy makers impose a
particular policy, they may not have a precise idea of producer
reactions.  Furthermore, policy makers do not control producers
reactions directly, rather they only guide them through the
subsidy, taxation and regulatory framework.  A unified model of
policy and policy reaction is as follows:

In this unified model, policy is chosen so that it maximizes the
satisfaction of the policy maker but is subject to the optimal
response of the producer.  This model is called a multi-level
model (Candler, Fortuny and McCarl 1981),  but is difficult to
solve.  However, it is an appropriate conceptualization of the
environmental policy process.

This problem has been found to be combinatorial in nature and in
possession of many local optimal (Candler, Fortuny and McCarl
1981, Bard 1985).  In addition results have shown that a mix of
good policies may result in a bad policy, so the problem needs to
be approached with care.  Results have also shown that radical
changes in policy may be better than fine tuning an existing
policy (Candler 1981).  This model is the subject of research on
a number of fronts and also is related to developments in optimal
control and other modeling contexts.

Caution: Don't Use Policy Objectives with Behavioral Response

Models

A common thought when looking at the above framework is why worry
about the producer objectives in framing the response?  Rather
why not impose the policy makers objectives and constraints along
with the produce response variables and constraints, then
maximize satisfaction from the policy outcomes.  In other words:
Why worry about maximization of the producer objective function?
Such a model follows:

This approach is wrong!  Its fallacy can be argued as follows.
In a programming model, the decision variable solution maximizes
the objective function.  Consider the following example: suppose
US policy makers were simultaneously interested in maximizing
producer income, minimizing soil erosion, and minimizing imported
oil.  Do you think that farmers would readily sacrifice income
earning potential to satisfy government desires?  I doubt it.

Government only guides the decisions made by individuals, it does
not specify them.  Clear counter examples exist in the
literature.  The economic theory of externalities indicates
individuals commonly generate unattractive social outcomes (i.e.
polluted water) because of divergences between social and private
values.  In addition, water conservation motivated incentive
programs have found conservation scheme adopters commonly
irrigate additional acres and increase total water use defeating
the conservation objective.  Thus, it is important to maintain
the distinction between government objectives and producer
responses.  Use of producer response models hopefully helps
forecast unanticipated outcomes.

PROPER SPECIFICATION OF PRODUCER RESPONSE MODELS

Given the difficulty in solving the model articulated above, the
state of the art in environmental modeling has generally involved
specification of response models which:

* predict producer response in the face of environmental
incentives.

* account for policy objectives; and

* can be used to do policy scenario analysis.

Significant differences arise in producer response models
formulated at the producer, regional and or nation-sector wide
levels.  Here I discuss all three but feel the last is the most
relevant, so spend more time on it.

Modeling the Response of Individual Price-Taking Producers

When the focus is on individual (or a small group) response, models are usually formulated assuming the producer is a price taker, not large enough to influence prices of traded products or factors. The main job in specifying such a model is the adequate depiction of the production response possibilities, constraints and objective function(s).

The first job is to identify variables, the largest set of which is usually the production possibilities. Here one often specifies multiple variables for production of each enterprise. For example, variables might depict the crop planted at different times with different irrigation systems and cultivation techniques. In an Indonesian study (McCarl and Van Holst Pellekaan 1982) rice variables were introduced for crops planted during different seasons using different varieties, fertilization techniques, cultivation practices and rotations. Other variables are commonly specified for factor acquisition possibilities such as hired labor, renting land and purchasing inputs. Variables may also involve diet formation and factor sale such as renting land to others or hiring family labor to others.

The constraints must be defined so that they adequately depict the limitations on the response choice. Often there are multiple constraints for a class of factors. Models commonly are constrained by monthly or finer disaggregations of labor, irrigation water, machinery and draft power. Constraints may also specify calorie and protein requirements for a family subsistence diet (Calkins 1981) as well as a refection of tastes and preferences.

The other important factor in the producer response model is the proper specification of objectives. The interaction of the constraints and variables usually allows thousands of possible solutions while the objective function picks the relevant solutions or solution set. In the Indonesia study, the objectives specified were profit maximization, risk avoidance and subsistence diet adequacy.

In general, production response models carry with them a number of assumptions. One is that they are a "typical" firms in a region. Such models are not usually statistically representative but are rather felt to depict production across a loosely-defined class of individuals. The models are usually set up relying on cross-section data commonly integrating producer and experimental data so as to fully portray production possibilities. Factors such as land, family labor, hired labor, water and land rental are assumed to either be available in fixed quantity or fixed price up to a maximum quantity.

Environmentally such models vary widely but the common approach is to include equations which impose regulatory limits or add up environmental items of interest. Policy relevant items can also be accounted for, commonly firm profits, labor employment, and production shipped off the farm among others are computed for

policy-maker consideration.


Farm Level Case Example 1 -- Indonesian Technology Prospects

This study involves supply response within Indonesian agriculture
(McCarl and Van Holst Pellekaan).  In this study, three farm
models were set up.  One was a "typical farm" model for a dryland
region in Southern Sumatra.  The other two depicted irrigated
production in Java under rainy season and year round irrigation
water supply.  The models depicted farm reactions to the
availability of several new technologies.

Technically, the variables included crop timing, multiple crop
sequences, fertilization rates, tillage power source, family diet
formation, labor hiring and labor sale.  The constraints included
monthly labor, land by period, tillage power availability,
subsistence, fertilizer response and technology availability.
The farm level objectives included income, risk and subsistence.
The policy outcomes of interest included the distribution across
farms of income, technology reliance, crop mix, employment, off-
farm marketable surplus, land use intensity, and irrigation water
usage.  Production data for the study were drawn from statistical
farm budgets, as well as a set of fertilization and multiple
cropping experiments conducted in farmers fields.

The models were used to examine alternative scenarios regarding
sensitivity of farm technology adoption and performance measures
to labor market conditions, product prices, risk attitudes,
family size, farm size, draft power source and farm type.  The
model solutions were used as input to studies examining:

* the prospects for food production,

* the types of incentives one needed to simulate non-rice crop
production;

* the implications of new technology for the value of year-round
water control projects; and

* the design of a sector-wide loan program.


Farm Level Case 2 -- Corn Byproducts for Biofuels

The second case involves U.S. midwest farms and corn-biomass
harvesting (Apland, Baker and McCarl 1981/82).  In this study,
farm reactions to incentives designed to stimulate the harvest of
corn stover for biofuels production were examined.   A farm model
was set up for a "typical" Indiana farm with emphasis on harvest-
time conditions.

Technically, the variables include crop timing, multiple-crop
sequencing, rotations, own and custom harvest, fertilization,
labor hiring and labor sale.  The constraints included bi-weekly
labor, land by period, machinery availability, a stochastic
distribution of harvest time available and associated yields,

crop rotation requirements.  The producer-model objectives
include income, risk and labor-leisure tradeoffs.  The policy
variables of interest include crop mix, stover harvest as it
varies by harvest conditions, income, employment, and risk
exposure.  Data for the study were drawn from extension budgets,
existing models, biomass-harvesting experiments and engineering
calculations.

The models were used to examine alternative scenarios regarding
harvest conditions,  harvest equipment, stover price, product
prices, hired labor prices.  The model analysis was done as a
follow up to a wider study (Tyner et al. 1979) directed toward
the U.S. Congress and consideration of the appropriate
agricultural synfuels component of energy policy.


Other Farm Level Environmental Studies

A wide variety of farm level studies have been done.  For
example, citing several that are directly related to
environmental matters:

* Cashman, Martin, and McCarl examined pesticide bans.

* Apland, McCarl, and Miller studied the different irrigation
equipment prices and risk attitudes as they influenced irrigation
adoption while Ziari, McCarl and Stockle examined irrigation
system adoption and in stream flow.

* Boggess, et al. examined the effects of different soil
conservation incentives.

* Bryant et al. examined the sensitivity of coastal farm
performance to proposed USEPA erosion regulations.


Regional Models


Probably the typical EPAT analysis would at least involve a
regional focus.  At such a level, one could use a set of
"representative" farm models chosen to jointly reflect the
component of regional production relevant to the study.  The
choice of representative farms  will not be discussed here
(interested readers should refer to the review in Onal and McCarl
1991).

The regional model contains the firm level representative farm
models plus additional features for factor and possibly some
product markets.  For example, the land rental market may need
reflect land rental rate determination across firms.  There also
may be regional limits for any hired labor, water, draft animals,
and machinery shared among the firms.  Yet another common
regional model characteristic is a less than full specification
of the firm submodels particularly in terms of the production
possibilities.  Discussion of why this is the case as well and

how to avoid problems appears in the sector modeling section.


Regional Case Study 1 -- Edwards Aquifer Water Allocation

The Edwards Aquifer (EA) in Central Texas is used by
agricultural, municipal and industrial interests while feeding
springs which support endangered species and recreation.
Regional growth has resulted in increased EA reliance and has
caused considerable fluctuation in springflow.  Aquifer recharge
varies widely with average pumping usage almost equal to average
recharge and thus, little left for springflow.  Management of the
EA has become a hot policy issue resulting most recently in the
declaration of the EA as a river.  An ongoing modeling exercise
has examined EA management issues (Dillon and McCarl 1991).  A
regional model was established which simultaneously depicts
agricultural production, municipal water usage, industrial water
usage and resultant springflow.

Technically, the model variables include pumping, crop
production, allowable crop mixes, irrigation development,
municipal usage, industrial usage, pumplift determination,
aquifer lever determination and springflow determination.  The
constraints include labor, land, crop mix adherence, aquifer
balance, water available by aquifer recharge state of nature,
pumplift, springflow limits, and usage limits.  The objective
maximizes expected regional welfare across the recharge
distribution and includes terms for net farm income, municipal
water consumers' surplus, municipal water supply cost, industrial
water consumers' surplus and industrial pumping cost.  The policy
variables of interest include regional welfare, springflow,
aquifer level, and pumping lift as well as the distribution
across parties of income, water usage, and water prices.  Data
for the study were drawn from extension farm budgets, county
cropping records, municipal and industrial water demand studies,
agricultural engineering  crop water requirement formulas, and an
aquifer hydrology simulator.

Model use has involved examination of potential management and
property right schemes, optimal water allocation, springflow
limits, usage limits, farmer nonparticipation in a water market,
population growth, and drought management.


Regional Case Study 2 -- Jordanian Cropping Pattern Policy

The Jordanian government supports a cropping pattern policy
designed to increase export revenues.  This policy imposes
mandatory acreage quotas.  A study was done by Bessler and McCarl
in conjunction with a Jordanian Government-USAID project and
Sigma One Corporation.  This study used a regional programming
model of the Jordanian agricultural sector under the assumption
that Jordan was a price taking country (a parallel study verified
this assumption).

Technically, the model variables include regional crop mixes,
water supply, tractors and hired labor acquisition as well as

country wide exports, imports and domestic consumption.  The
constraints include regional labor, land, water, crop mix
adherence, cropping pattern limits, and tractors as well as
national commodity balances.  The objective maximizes net
agricultural income.  The policy variables of interest include
farm income, cropped area, employment, machinery use, cropping
pattern, water use, trade balance and domestic food consumption.
Data for the study were drawn from extension farm budgets,
regional cropping records, government policy documents, and
regional trade statistics.

Model use involved examination of potential returns to a
relaxation of the cropping pattern scheme including complete
removal.  Conclusions were drawn about the types of crops that
would be grown under policy relaxation and the costs of the
cropping pattern policy.


Other Regional Studies

A number of other regional studies have been done.  For example:

* Irrigation, machinery, dairy herd management, rural development
and salinity control that were studied in the context of Mexican
agriculture (Norton and Solis 1983).

* Agricultural policy in Northeast Brazil was examined (Kutcher
and Scandizzo 1981).

* The agricultural benefits of salinity control in the Red River
Basin in Texas are being examined by the author.

* Foreign trade conditions in Nicaragua were studied (Fajardo,
McCarl and Thompson 1981).

* Irrigation/Hydropower tradeoffs were studied in the Pacific
Northwest (McCarl and Parandvash 1988).

* Waste management and recycling were studied (Clayton and McCarl
1979).

* Regional shrimp fishery management was considered in Onal et
al. 1991)


National - Sectoral Models


Considerable EPAT environmental action will probably involve
policies or environmental forces which influence the entire
country and agricultural sector.  Sector models are relevant
producer reaction models in such a case (I will not cover multi-
sector or general-equilibrium modeling).   Sector modeling
differs from firm or regional modeling in terms of pricing and
representative firm detail.

The pricing difference arises since sectoral forces usually render product and factor prices a function of the quantity produced and or consumed (i.e. demand and supply curves need to be considered).  As a consequence, care is needed in specifying the appropriate model.

Consider first the recipe for an inappropriate model.  Suppose one is modeling Egyptian long-stem cotton production.  In doing such, suppose a linear rest of world demand curve is formed and a price times quantity term in the objective function.  Thus, the model has a term maximizing Egyptian export revenue.  Under such a case, a model generates the solution of where Egyptian producers act as perfectly discriminating monopolists in cotton exporting (McCarl and Spreen, 1980, or Takayama and Judge, 1971, review evidence pertinent to this statement).  Such a solution is not consistent with observed behavior.

The common way of fixing such problems is to alter the objective function so one maximizes the area underneath the demand curve and above the supply curve which is called consumers' plus producers' surplus. Such a model simulates production in a perfectly competitive market(see the original development in Samuelson and the literature review in McCarl and Spreen 1980). Use of such an objective function complicates other matters, namely when risk exposure minimization is an important objective of producers and price risk is relevant then risk is an endogenous function and the appropriate way of preventing monopolistic risk avoidance behavior has not been fully worked out, nor has aggregation under risk (see the paper by Hazell and Scandizzo, 1974, or the paper by Lambert, McCarl, and Kaylen, 1992, for a discussion of these issues).  Fortunately, in many circumstances, risk aversion has been found to be near zero when operating with aggregate level data.

The other major characteristic of sector models involves aggregation.  Clearly in many sector studies, it is impossible to develop a full set of representative firm models for inclusion in the sectoral model.  As a consequence, sectoral models usually deal with much more aggregate firm representations(i.e. one per state).  This can introduce significant aggregation error if one inadequately depicts response possibilities.  An aggregation error example appears in the contrast of two studies involving with the potential of producing energy from U.S. agriculture corn byproducts.  One study (Apland, McCarl and Baker 1981/82) used a firm level model and found when the value of corn byproducts was increased corn acreage declined.  This reflected a crop-mix change induced by limited-harvest resources interacting with the increased harvest requirements for corn byproducts.  However a sector-model analysis of the same problem (Tyner et al, 1979, and Bender and McCarl 1992) showed corn production increased with the corn-byproduct price.  Clearly the aggregate representation exhibited aggregation error predicting a different kind of supply response.  The firm model probably also overstated reaction since it used a fixed-price assumption and did not permit the firm to significantly restructure harvest capacity.  Some answer between the two models may be the most appropriate. The lesson is that aggregate models should have a farm-level response component

which adequately reflects response to the types of policies being
investigated.  This leads to two types of difficulties and their
solutions.

Sector modelers and analysts must develop data reflecting an
adequate set of production possibilities.  Often one develops
production possibilities based upon budgets generated by
extension personnel or statistical surveys.  Such budgets usually
reflect a production pattern which existed at a point in time.
As such they do not represent the available set of possibilities
just the choice of the moment.  Furthermore, the pattern given is
conditioned by the particular set of factor and product prices in
place at the time.  If the corn price is high relative to the
fertilizer price, fertilizer use will be high.  On the other
hand, if the corn price is low relative to the fertilizer, little
fertilizer will be used.  Either way, the full set of fertilizer
alternatives will not appear if sampling.  So how do you depict
the relevant production possibilities?  In such a case, one may
well need to rely on expert, experimental or crop-simulator data
(Dillon, Mjelde and McCarl 1989) to modify the budget data and
generate production alternatives.

Second, one cannot usually afford to depict all different ways of
producing a crop and all the constraints which influence choice
on all farms.  However, the producer response will take into
account the technical forces, dietary preferences, resource
restrictions and rotations which lead to a particular choice.  In
such a case, I recommend restricting the crop mix to fall within
some combination of observed crop mixes (as argued in McCarl,
1982, and Onal and McCarl 1991).  The observed crop mixes have
restrictions implicitly coded into them on the firms' employment
of resources and rotations.  The historical mixes may need to be
augmented for an environmental analysis if the actions are
anticipated to cause production outside the historically observed
crop mixes.  If this is the case, then either use expert opinion
or auxiliary farm level models (as done in Hamilton, McCarl, and
Adams 1985) to make a richer productions possibilities set.


Sectoral Case Study 1 -- Egyptian Water Control

A study was done regarding water control and cropping patterns in
Egypt.  By the  mid 1980's, the strategic reserve of water in the
High Aswan Dam had fallen from a two-year to a two-month supply.
But, Egyptian water-use patterns did not adjust substantially.
As a consequence a study was undertaken to examine High Aswan Dam
release and cropping-pattern policy in the face of future
prospects for water availability.  This was done using an
Egyptian agricultural sector model (McCarl and Attia 1988) in
conjunction with a High Aswan Dam-simulation model.

Technically, the sector model variables include a five-region
breakdown of crop production, crop processing, livestock feeding,
domestic consumption, exports, imports, transport, hired labor,
subsidies and taxes. The constraints include regional labor,
land, vegetable limits, cropping pattern limits and livestock
nutritional characteristics as well as national commodity

balances and water availability.  The objective maximizes net
agricultural consumers' and producers' surplus after imposition
of government taxes and subsidies.  The policy variables of
interest include consumers welfare, price levels, farm income,
cropped area, employment, government subsidy costs, government
tax revenues, water usage, imports, exports, trade balance and
domestic food consumption.  Data for the study were drawn from
agricultural ministry budgets, regional cropping records,
government statistical documents, consumer demand studies and
world trade regional trade studies.

The sectoral model was utilized to value the effects of
alternative water release levels coupled with alternative
cropping patterns.  Cropping pattern commitments were assumed to
start before full information on the available water was known.
The High Aswan dam simulator was utilized to predict carry over
water in the dam as well as the value of the hydroelectric output
under various release policies and water years.  The sector model
was used to predict the agricultural benefits of various water
releases under alternative cropping patterns.  In turn, a
decision theory framework was utilized to examine economic
returns and their variability as well as retained water across
cropping pattern and dam release policies.


Sectoral Case Study 2 -- Ozone Control

A common use of sectoral models by the author has involved the
environmental assessment of changes in air quality.  One study
involved the agricultural benefits of alternative U.S. ozone
standards.  There a U.S. agricultural sector model was employed
to study the effects of changes in ozone concentrations (Adams,
Hamilton and McCarl 1986).

Technically, the model variables included activities for a 63-
region breakdown of crop production, crop-mix choice, irrigation,
livestock production, labor supply, land supply, water supply,
processing, livestock feeding, domestic consumption, exports,
imports, fixed price input acquisition and farm program
subsidies.  The constraints include regional labor, land, water,
crop mixes, policy restrictions, and livestock feed needs as well
as national commodity balances.  The objective maximizes net
agricultural consumers' and producers' surplus after imposition
of government subsidies.  The policy variables of interest
include consumers welfare, price levels, farm income, cropped
area, employment, government subsidy costs,  water usage,
imports, exports, trade balance and domestic food consumption.
Data for the study were drawn from USDA cost of production
surveys, extension farm budgets, regional cropping records,
government statistical documents, consumer demand studies,
experimental studies of ozone concentration effects on crop
yields and world trade studies.

The model was utilized in conjunction with the crop yield and
water use results of ozone chamber experiments to forecast the
agricultural sector consequences of ozone concentration
variations (Adams, Hamilton and McCarl 1986).  The study was

incorporated as part of a report to Congress and the agricultural benefits were used to partially justify changes in clean air regulations. Similar analyses were also done on the effects of acid rain(Adams, Callaway and McCarl 1986), carbon sequestration (Adams et al. 1991) and global climatic change (Adams et al. 1989,1990).


Other Sectoral Studies

A number of other sectoral studies have been done. For example:

* There were a number of studies done involving policies aimed toward irrigation projects, and other development issues in the context of Mexican agriculture (Norton and Solis 1983)

* Studies have been done regarding U.S. erosion policy (Heady and Srivistava 1975)  as well as Alt et al., pesticide bans (Burton and Martin 1987), fertilizer use changes (Meister, Chen and Heady 1978) and biofuels production (Tyner et al 1979).

* Studies have been done on Indus Basin water management (O'Mara and Duloy 1984).


An Aside -- Doing a Programming Study


In passing, it is worthwhile recommending the usage of GAMS software (Brooke Kendrick and Meeraus 1988) for doing studies in this arena.  This software permits solution of large models on micro computers, facilitates documentation and later use of models,  and allows use by varied personnel.  I feel these attributes would be highly desirable in the EPAT environment.  I believe the sister APAP project runs training sessions in GAMS.


CONCLUSIONS


This paper has only scratched the surface of the very large mathematical programming, environmental analysis area.  Analyses in this area generally involve the quest for  optimal policy. This question may be approached formally through multi-level programming or informally through scenario analysis.  At this point, operational issues largely dictate scenario analysis, but research is ongoing on formal optimal policy discovery.  In either context, mathematical programming provides a useful framework to resolve questions about how producers would respond to environmental incentive and regulatory programs.  Models permit investigation of possible policies so as to both steer producer responses and avoid unanticipated responses. Fundamentally, it is important to recognize  policy objectives or

items of concern, then build producer- response models which forecast how those objectives would be affected if policies were implemented.

REFERENCES


Adams, D., R.M. Adams, J.M. Callaway, C.C. Chang and B.A. McCarl. 1991. THE ECONOMIC OF SEQUESTERING CARBON ON AGRICULTURAL LAND IN THE U.S.: A PRELIMINARY ANALYSIS OF SOCIAL COST AND IMPACTS ON TIMBER. Invited paper presented at the Annual Western Economics Association Conference, Seattle, Washington, June 29-July 3.

Adams, R.M., J.M. Callaway and B.A. McCarl. 1986. "Pollution, Agriculture and Social Welfare: The Case of Acid Deposition." CANADIAN JOURNAL OF AGRICULTURAL ECONOMICS. 34: 3-19.

Adams, R.M., J.D. Glyer and B.A. McCarl. 1989. "The Economic Effects of Climate Change on U.S. Agriculture: A Preliminary Assessment." The Potential Effects of Global Climate Change on the United States. Report to Congress by the U.S. Environmental Protection Agency.

Adams, R.M., S.A. Hamilton and B.A. McCarl. 1986. "The Benefits of Pollution Control: The Case of Ozone and U.S. Agriculture." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 68: 886-893.

Adams, R.M., B.A. McCarl, D.J. Dudek and J.D. Glyer. 1988. "Implications of Global Climate Change for Western Agriculture." WESTERN JOURNAL OF ECONOMICS. 13: 348-356.

Adams, R.M., C. Rosenzweig, R.M. Peart, J.T. Richie, B.A. McCarl, J.D. Glyer, R.B. Curry, J.W. Jones, K.J. Boote and L.H. Allen. 1990. "Global Climate Change and U.S. Agriculture." NATURE. 345: 219-224.

Alt, K., J. Atwood, K. Bryant, C.C. Chang, R. Lacewell and B.A. McCarl. 1992. AGRICULTURAL IMPACTS OF REQUIRING ALTERNATIVE CONSERVATION SYSTEMS IN COASTAL ZONE DRAINAGE BASINS. Draft U.S. Department of Agriculture's Soil Conservation Service report, TAES/SCS Cooperative Project on Natural Resource Modeling and Policy Analysis.

Apland, J.D., B.A. McCarl and T.G. Baker. 1981/1982. "Crop Residue for Energy Generation: A Prototype Application to Midwestern U.S.A. Grain Farms." ENERGY IN AGRICULTURE. 1: 55-70.

Apland, J.D., B.A. McCarl and W.L. Miller. 1980. "Risk and the Demand for Supplemental Irrigation: A Case Study in the Corn Belt." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 62: 142-145.

Bard, J.F. 1985. "Geometric and Algorithmic Developments for a Hierarchical Planning Problem." EUROPEAN JOURNAL OF OPERATIONAL RESEARCH. 19: 372-383.

Barnett, D.A., B. Blake and B.A. McCarl. 1982. "Goal Programming via Multi-Dimensional Scaling Applied to Senegalese Subsistence Farms." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 64: 720-727.

Bender, D.A. and B.A. McCarl. 1992. "Energy Crop Selection Using Linear Programming." In ANALYSIS OF AGRICULTURAL ENERGY SYSTEMS. Edited by R.M. Peart, New York & London: Elsevier Applied Science Publishers, 57-82.

Bessler, D.A. and B.A. McCarl. 1989. AN ASSESSMENT OF THE ECONOMIC IMPACT OF THE JORDANIAN AGRICULTURAL CROPPING PATTERN PROGRAM. Report under Agricultural Marketing Development Project, U.S. Agency for International Development Project No. 278-0274.

Boggess, W.G. and E.O. Heady. 1981. "A Sector Analysis of Alternative Income Support and Soil Conservation Policies." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 63: 618-628.

Brandao, E., B.A. McCarl and G.E. Schuh. 1984. "Predicting the Impact of New Cropping Practices Upon Subsistence Farming: A Farm Level Analysis in Brazil." WESTERN JOURNAL OF AGRICULTURAL ECONOMICS. 9: 329-341.

Brink, L. and B.A. McCarl. 1978. "The Expected Income-Risk Trade-off Among Corn Belt Crop Farmers." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 60: 259-63.

Brooke, A., D. Kendrick and A. Meeraus. 1988. GAMS: A USER'S GUIDE. Redwood City: The Scientific Press, Redwood.

Bryant, K.J., J.D. Atwood, R.D. Lacewell, V.D. Lansford and B.A. McCarl. 1992. FARM LEVEL IMPACTS OF THE COASTAL ZONE MANAGEMENT ACT: PROPOSED EROSION REGULATIONS. Presented at the Soil and Water Conservation Society's Annual Meeting. Baltimore, August 9-12.

Burton, R.O. and M.A. Martin. 1987. "Restrictions on Herbicide Use: An Analysis of the Economic Impacts on U.S. Agriculture." NORTHERN CENTRAL JOURNAL OF AGRICULTURAL ECONOMICS. 9: 181-194.

Calkins, P.H. 1981. "Nutritional Adaptations of Linear Programming for Planning Rural Development." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 63: 247-254.

Candler, W. and M. Boeljhe. 1977. "Use of Linear Programming in Capital Budgeting with Multiple Goals." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 53: 325-330.

Candler, W.V., J. Fortuny-Amat and B.A. McCarl. 1981. "The Potential Role of Multilevel Programming in Agricultural

Economics."  AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS.  63: 521-531.

Cashman, C.M., M.A. Martin and B.A. McCarl.  1981.  "Economic Consequences of Bans on  Corn (Zea Mays) and Soybean (Glycine Max) Herbicides Commonly Used on Indiana Farms."  WEED SCIENCE. 29: 323-328.

Chang, C.C., B.A. McCarl, J.W. Mjelde and J.W. Richardson.  1992.

"Sectoral Implications of Farm Program Modifications."  AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS.  74: 38-49.

Clayton, K.C. and B.A. McCarl.  1979.  "Management of Solid Waste in Systems Including Nonmetropolitan Areas, with Emphasis on Resource Recovery."  NORTH CENTRAL JOURNAL OF AGRICULTURAL ECONOMICS.  1: 61-72.

Dillon, C.R. and B.A. McCarl.  1991.  AN ECONOMIC INVESTIGATION OF WATER USE TRADEOFFS IN THE EDWARDS AQUIFER.  Paper presented at the Southwestern Social Science Association Meeting, San Antonio, TX.

Dillon, C.R., J.W. Mjelde and B.A. McCarl.  1989.  "Biophysical Simulation in Support of Crop Production Decisions: A Case Study in the Blacklands Region of Texas."  SOUTHERN JOURNAL OF AGRICULTURAL ECONOMICS.  21: 73-86.

Fajardo, D., B.A. McCarl and R.L. Thompson.  1981.  "A Multicommodity Analysis of Trade Policy Effects: The Case of Nicaraguan Agriculture."  AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS.  63: 23-31.

Hamilton, S.A., B.A. McCarl and R.M. Adams.  1985.  "The Effect of Aggregate Response Assumptions on Environmental Impact Analyses."  AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS.  67: 407-413.

Hazell, P.B.R.  1979.  "Endogenous Input Prices in Linear Programming Models."  AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 61: 476-481.

Hazell, P.B.R. and P.L. Scandizzo.  1974.  "Competitive Demand Structures Under Risk In Agricultural Linear Programming Models." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS.  56: 235-244.

Heady, E.O. and U.K. Srivistava.  1975.  SPATIAL SECTOR PROGRAMMING MODELS IN AGRICULTURE.  Ames: Iowa State University Press.

Kutcher, G.P. and P.L. Scandizzo.  1981.  THE AGRICULTURAL ECONOMY OF NORTHEAST BRAZIL.  Baltimore: The Johns Hopkins University Press.

Lambert, D.K., B.A. McCarl and M.S. Kaylen.  1992.  UNCERTAIN YIELD AND ADAPTIVE BEHAVIOR IN SECTOR MODELS.  Unpublished journal draft, Texas A&M University.

McCarl, B.A. 1982. "Cropping Activities in Agricultural Sector Models: A Methodological Proposal." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 64: 768-772.

McCarl, B.A. and B. Attia. 1988. AN EXAMINATION OF LAKE NASSAR OPERATING POLICIES AND ASSOCIATED CROPPING PATTERNS. Unpublished report under USAID Project.

McCarl, B.A. and G.H. Parandvash. 1988. "Irrigation Development versus Hydroelectric Generation: Can Interruptible Irrigation Play a Role?" WESTERN JOURNAL OF AGRICULTURAL ECONOMICS. 13: 267-276.

McCarl, B.A. and T.H. Spreen. 1980. "Price Endogenous Mathematical Programming as a Tool for Sector Analysis." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 62: 87-102.

McCarl, B.A. and J. Van Holst Pellekaan. 1982. "A Farm Level Linear Programming Analysis of Dry-Land and Wet-Land Food Crop Production." ANALYSIS OF POTENTIAL STRATEGIES FOR INCREASING NON-RICE FOOD CROP PRODUCTION. Annex to World Bank Report, May 25.

Meister, A.D., C.C. Chen and E.O. Heady. 1978. QUADRATIC PROGRAMMING MODELS APPLIED TO AGRICULTURE POLICIES. Ames: Iowa State University Press.

Norton, R.D. and L.M. Solis. 1983. THE BOOK OF CHAC: PROGRAMMING STUDIES FOR MEXICAN AGRICULTURE. Published for the World Bank. Baltimore: The Johns Hopkins University Press.

O'Mara, G.T. and J.H. Duloy. 1984. "Modeling Efficient Water Allocation in a Conjunctive Use Regime: The Indus Basin of Pakistan." WATER RESOURCES RESEARCH. 20: 1489-1498.

Onal, H. and B.A. McCarl. 1991. "Exact Aggregation in Mathematical Programming Sector Models." CANADIAN JOURNAL OF AGRICULTURAL ECONOMICS. 39: 319-334.

Onal, H., B.A. McCarl, W.L. Griffin and G. Mattlock. 1991. "A Bioeconomic Analysis of the Texas Shrimp Fishery and Its Optimal Management." AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS. 73: 1161-1170.

Romero, C. 1991. HANDBOOK OF CRITICAL ISSUES IN GOAL PROGRAMMING. Oxford: Pergamon Press.

Samuelson, P.A. 1952. "Spatial Price Equilibrium and Linear Programming." AMERICAN ECONOMIC REVIEW. 42: 283-303.

Steuer, R. 1978. "Vector Maximization Gradient Core Contraction Techniques." MULTIPLE CRITERIA PROBLEM SOLVING. Edited by S. Zoints, Berlin: Springer-Verlag, 462-481.

Takayama, T. and G.G. Judge. 1971. SPATIAL AND TEMPORAL PRICE AND ALLOCATION MODELS. Amsterdam: North Holland Publishing

Company.

Tyner, W., B.A. McCarl, et al.  1979.  THE POTENTIAL OF PRODUCING
ENERGY FROM AGRICULTURE.  Final Report to the U.S. Congress
Office of Technology Assessment.  School of Agriculture, Purdue
University, May.

Weins, T.B.  1976.  "Peasant Risk Aversion and Allocative
Behavior: A Quadratic Programming Experiment."  AMERICAN JOURNAL
OF AGRICULTURAL ECONOMICS.  58: 629-635.

Ziari, H.A., B.A. McCarl and C. Stockle.  1992.  THE ECONOMIC
FEASIBILITY OF RUN-OFF IMPOUNDMENTS FOR SUPPLEMENTAL IRRIGATION
IN BLACKLANDS REGION OF TEXAS.  Unpublished journal draft,Texas
A&M University.

ADDENDUM

INTRODUCTION

Apparently there has been interest in the nature of the case
example findings within my manuscript "Mathematical Programming
for the Resource Policy Appraisal Under Multiple Objectives"
published by the Environmental and Natural Resources Policy and
Training Project as Working Paper No. 6 in November, 1992.  This
addendum provides additional information on findings within each
case study.  Beyond that I would urge readers interested in more
detail to consult the references.

Farm Level Case Example 1 - Indonesian Technology Prospects (page
10)

Several findings were generated.  First, it was found that the
prospects for food production, particularly rice, were bright as
the technologies examined were found to have considerable
potential to expand production in an economically efficient
manner.  In fact, the study was done at a time when Indonesia was
just on the border of being food defficient (late 1970's), but
over the few years after the study the country moved forward food
self sufficiency with expansions in food exports partially due to
technological change, thus the results of the study were borne
out.  Second, conclusions were made within the study about the
need, particularly in the upland areas, for credit and other
types of incentive schemes, directed toward farming systems
rather than crop specific programs.  Third, a technology that
allowed one to get two rice crops out of wet season water was
investigated.  Within the study, the results of this technology

were compared to year-round water management, it was found that the presence of the cropping technology reduced the returns to year-round water control irrigation infrastructure by over 80 percent.  In turn, this finding led to policy debates within the sponsoring organization as to the appropriate levels of investment and eventually a reappraisal of a large lending program.  Finally, the results were used in support of arguments for additional research funding in the context of a sector lending program.

Farm Level Case Study 2 - Corn Byproducts for Biofuels (page 11)

The results of this study showed that:
1. crop residue is an expensive source of energy;

2. producers would produce a highly variable amount of crop residue depending on harvest time weather conditions;

3. crop residue harvest competed dramatically with harvesting of other crops and caused a crop mix alteration; namely corn acreage was reduced with wheat and soybean acreage increased, allowing fall harvest time to be freed up;

4. larger harvesting equipment and new technology would help the situation;

5. in the short-run, the supply curve of residue would be highly inelastic, and;

6. the long-run supply curve was very responsive at low prices with the quantity supplied between $30 and $40 a ton of residue varying by a factor of 2.

Regional Case Study 1 - Edwards Water Allocation (page 13)

The results of this study indicated that emerging changes in water consumption patterns in the region would lead to a disparity of water use values between nonagricultural and agricultural users.  This indicates that it would be most useful if ground water rights and an associated market for such rights were put in place to allow transfer of water from the low to the high value users.  Second, agriculture was found to be a very vulnerable sector from an overall economic optimum perspective as demand grows, since agriculture is a much lower valued user.  Third, protection of springflows was found to influence returns, costing as much as $40 per acre foot of water.  Fourth, schemes which limited the sectoral amount of water without allowing transfer between the sectors were found to be efficient at first but to have higher welfare costs as time went on.  Finally, it was found beneficial that agriculture use water in periods of high flow and not suspend water use in periods of low flow

thereby allowing water use by the highest valued users in the
critical periods but permitting beneficial agricultural
production in the water surplus periods.

Regional Case Study 2 - Jordanian Cropping Pattern Policy (page
13)

The basic conclusion of this study was that the cropping pattern
policy which limited the quantity of high-valued vegetable export
crops was economically costly.  It appears that by suspending the
policy and allowing larger quantities of certain exports to be
produced, the prices received would not change and producer
welfare would increase.

Sectoral Case Study 1 - Egyptian Water Control (page 17)

The basic results of this study were two.  First, by employing a
conservative water release strategy and cutting back on the heavy
water using rice and sugar crops, that a substantial opportunity
for increasing the water supply available from in the High Aswan
Dam and the efficiency of water use existed even in the face of
potentially serious drought effects.  Second, this study was
completed before one of the larger floods in recent history and
this was found to be unfortunate.  The subsequent floods and
level of inflows in the last several years made the drought
oriented study of little interest to policy makers.  In a related
study, the same model was also used to look at incentive and
pricing policies and its effects on land allocation and the value
of water.  It was found that pricing policies were a very big
factor in farm returns and production choice.  Lowering in price
differentials between farm production and exports caused by
government policy would cause greater production of certain farm
commodities, increase social welfare and, in fact, increase
government tax revenues.

Sectoral Case Study 2 - Ozone Control (page 17)

The results of this study showed that agriculture was very
vulnerable to ozone with roughly a $200 million change in the net
welfare of the agricultural economy.  Comparison of this outcome
with the cost of cleaning up ozone, made agriculture almost large
enough in benefits to justify the anticipated provisions on its
own.  The acid rain analysis showed that acid rain benefits
agriculture.  The carbon sequestration analysis showed
substantial implications for agriculture from increases in tree
planting to prevent global climate change and that expanded tree
planting would lead to a reduction in welfare and activity in the
forest sector, the global climate change effects have, in the

most recent work done by the author, been shown to be positive for the U.S. agricultural economy.

In all of these case studies, the basic findings were used to generate a mixture of qualitative and quantitative insights regarding the potential performance of the modeled entity. Implications were drawn for overall economic performance as well as income distribution, and when possible environmental attributes.

.