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TR052A

Processes for Identifying Regional Influences of and Responses to Increasing Atmospheric CO₂ and Climate Change - The MINK Project

An Overview

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An Overview

Prepared by:
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Resources for the Future
Washington, DC

Under Contract No. DE-AC06-76RLO1830

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NOTE TO READERS

This Overview report explains the rationale for and the methodology used in conduct of the study "Processes for Identifying Regional Influences of and Responses to Increasing Atmospheric CO₂ and Climate Change - The MINK Project" commissioned by the U.S. Department of Energy. The major findings of the study are also presented in this overview, which accompanies a series of six reports in which the requisite technical details on methodology, sectoral analyses and integrated analysis of climate change impacts and responses are provided in detail. The reports are:

- I. Background and Baseline - N.J. Rosenberg, M.D. Bowes, P.R. Crosson, J. Darmstadter, W.E. Easterling III, K.D. Frederick, M.S. McKenney, R.A. Sedjo, L.A. Katz and K. M. Lemon
- IIA. Agricultural Production and Resource Use in the MINK Region Without and With Climate Change - P. R. Crosson and L.A. Katz with J. Wingard
- IIB. A Farm-Level Simulation of the Effects of Climate Change on Crop Productivity in the MINK Region - W.E. Easterling, III, M. McKenney, N.J. Rosenberg and K. M. Lemon
- III. Forest Resources - M.D. Bowes and R.A. Sedjo
- IV. Water Resources - K.D. Frederick
- V. Energy - J. Darmstadter
- VI. Consequences of Climate Change for the MINK Economy: Impacts and Responses - M.D. Bowes and P.R. Crosson

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PROCESSES FOR IDENTIFYING REGIONAL INFLUENCES
OF AND RESPONSES TO INCREASING ATMOSPHERIC CO₂
AND CLIMATE CHANGE - THE MINK PROJECT

AN OVERVIEW

Norman J. Rosenberg and Pierre R. Crosson

1. Introduction

Scientists believe that a serious change in the climate of the earth could occur in the course of the next two to five decades as a result of warming caused by the rapid accumulation of radiatively active trace gases in the atmosphere. There is concern that not only the amount of warming but the rate at which it occurs could be unprecedented, at least since the current interglacial period began.

Scientific uncertainties remain in our understanding of the climatic changes that may follow from greenhouse warming. Nevertheless, large and rapid changes in regional climate are conceivable. General circulation models (GCMs) predict changes for the central U.S. as large as an 8°C increase in mean summertime temperature accompanied by a 1 mm/day decrease in mean precipitation. Most predictions are less extreme but, so long as the direction of change is credible, efforts are warranted to identify just what kinds of impacts to expect if society chooses to allow climate to change or cannot stop it from changing, and just what might be done to adjust to those impacts.

Additionally, it is known from the results of laboratory and growth chamber studies that when carbon dioxide, one of the primary greenhouse gases, increases in concentration in the atmosphere, plants respond with increased rates of photosynthesis and reduced rates of evapotranspiration and hence with improved water use efficiency--yield/unit of water consumed.

However, the strength of the CO₂ "fertilization effect" under actual field conditions still is uncertain.

Three broad policy strategies for dealing with prospective climate change are possible. One is to do nothing, accepting whatever change is in store and depending on induced individual and institutional responses to hold the consequences of change within acceptable limits. Another strategy is to adopt policies to facilitate adaptive responses, and the third is a set of policies designed to reduce greenhouse gas emissions sufficiently to achieve acceptable warming and associated climatic change.

Each of the three policy strategies has its adherents. However, fruitful discussion of the merits of each strategy is inhibited by the great scientific uncertainty concerning the amount and regional incidence of prospective climate change, and its socio-economic consequences. The discussion is impeded also by the absence of well-developed methodologies for the study of the consequences.

The MINK study (origin of the name MINK is explained below) does not deal with the issue of scientific uncertainty. Its aim instead is to improve the methodological base for assessment of the regional impacts of climate change and of responses to it. What needs to be done?

2. Methodological Needs

Four methodological inadequacies typify most prior studies of the impacts of climate change.

1) The climate of tomorrow is imposed abruptly on the world of today.

However, significant climatic impacts of greenhouse warming are unlikely for at least the next few decades and possibly longer. If history is any guide regional vulnerabilities and capacities

for adaptation will change during that time. Hence, impacts of climate change and responses will almost certainly be quite different in the future than they would be today.

- 2) The natural temporal and spatial variability of climate characteristic of large regions is ignored. The imposition of fixed temperature and precipitation changes predicted by general circulation models on grid boxes hundreds of kilometers on a side does not allow the natural intra-regional variability in climate to be expressed and may, therefore, provide biased results as to the impacts of climate change.
- 3) The complexity of the regional economy, its linkages with the rest of the world, and the place in it of the natural resource-based industries and other economic sectors are not taken into full account. Certain sectors, e.g., agriculture, forestry, and water are apparently more sensitive to climate than others. However, all sectors of the regional economy and the interactions among sectors must be considered if the real impact of climate change on a region is to be understood.
- 4) The full range of available technologies, management techniques, and policy tools that can lessen (or capitalize on) the impacts of climate change is not considered. There are many types of adjustments and adaptations within the limits of current technology and many foreseeable that might be applied to moderate the negative effects of climate change and/or capitalize on its positive impacts.

In an effort to overcome these inadequacies and strengthen methodology for climate impacts assessment four organizations came together in a program supported by the Department of Energy, Office of Health and Environmental Research. Resources for the Future (RFF) has been responsible for the analytical aspects of the program, Oak Ridge National Laboratory (ORNL) for data bases and geographical information systems, Sigma Xi for outreach, and Pacific Northwest Laboratories (PNL) for coordination. Sigma Xi and PNL were also involved in analysis of the uncertainties involved in the climate impact assessment methodology developed under this program.

3. The Analytical Framework

To overcome the methodological inadequacies described above an analytical framework was developed which aims to:

- 1) provide baseline information on current functioning of regional-scale economies and how they might develop in the future in the absence of climate change.
- 2) analyze how various kinds of climatic change may alter baseline resource productivity, e.g., crop production, forest output, runoff to rivers, and water storage.
- 3) study the ways in which the primary enterprises affected, e.g., farms, timber companies, water resource districts, may respond to these first-order effects.
- 4) study how the responses of primary enterprises may feed-back on the regional economy as a whole.

The analysis consists of four specific tasks and a set of subtasks as follows:

- Task A. Current baseline description of the region
- Tasks B. Imposition of a climate change on the current baseline
 - B₁.) Climate change only, no adaptation
 - B₂.) Climate change plus 100 ppm increase (above the current 350 ppm) in atmospheric CO₂
 - B_{3.1}, B₁ with currently available adaptation techniques
 - B_{3.2}, B₂ with currently available adaptation techniques and higher CO₂
- Task C. Baseline description of the region in the future
- Tasks D. Imposition of a climate change on the future baseline
 - D₁.) Climate change only, no adaptation
 - D₂.) Climate change plus 100 ppm increase in atmospheric CO₂
 - D_{3.1}, D₁ with future adaptation technologies
 - D_{3.2}, D₂ with future adaptation technologies and higher CO₂

4. The Region of Study and the Climate Change

In the first test of the methodology four adjacent states in the central United States--Missouri, Iowa, Nebraska, and Kansas (thus the MINK Region) were chosen for study. Relative to the rest of the nation the MINK economy is specialized in natural resource-based sectors most likely to be impacted by climate change. Also, certain GCMs predict dire changes in climate for the region as a consequence of global warming. The region encompasses portions of four major U.S. land resource areas: the Central Feed Grains and Livestock Region, East and Central Farming and Forest

Region, the Central Great Plains Winter Wheat and Range Region, and Western Great Plains Range and Irrigated Region.

Far removed from moderating influences of large bodies of water, the MINK region is typically continental and characterized by large seasonal swings in temperature and precipitation. Winters are cold and dry, summers hot. Precipitation declines sharply from east to west in the region. Length of the growing season, defined as the period between last frost in spring and first in fall, varies across the region from 200 days in the southeast to 120 days in the northwest. The region is subject to severe and sometimes protracted droughts.

For the purposes of the first study we chose to develop a scenario of climate change drawing on a segment of the historic record--the decade of the 1930s--to provide an "analog" of anticipated climatic change. The climate of 1931-40 was compared with that of the period currently defined by World Meteorological Organization convention as the 'normal', i.e., 1951-80. On average, the 1930s in MINK were hotter and drier than the present climate, but not in all places and not at all times. Nonetheless, the analog climate is generally consistent with GCM predictions for the MINK region sometime in the first half of the coming century.

5. Results of the Task Analyses

5.1 Task A: The Current Baseline

In Task A, the baseline, RFF analysts prepared a thorough account of the regional economy in MINK as it functions currently, with particular emphasis given to agriculture, forestry, water resources, and energy. Some important characteristics and statistical markers describing the region drawn from Report I are given here by sector.

Agriculture: The MINK region is more specialized in agriculture than the rest of the U.S; the percentage of farm income in total income being more than three times as much as in the rest of the nation. The region in the 1980s produced 34 percent of the nation's corn for grain, 30 percent of its soybeans and winter wheat, and 50 percent of its grain sorghum. Average yields of these crops were higher and production costs lower than in the rest of the nation. Nebraska had 64 percent and Kansas 30 percent of the irrigated land in the region. MINK in the 1980s produced 28 percent of the nation's cattle and calves and 42 percent of its hogs.

While agriculture in the MINK region has a smaller share of the economy than the manufacturing and service sectors its importance to the MINK economy and, hence, the region's vulnerability to climate change is significant because (a) a substantial amount of manufacturing in MINK is directed to processing farm outputs and manufacture of farm inputs (meat packing; fertilizers, machinery) and (b) agriculture's percentage contribution to regional exports--the key element in the economic base of the region--is several times greater than its contribution to regional income.

Forestry: Forestry is of more limited importance in the region, commercial forestry being confined primarily to the Ozark region in southeastern Missouri. The forests there are not highly productive but are actively harvested. Most of the forests are in the hands of private farmers who have converted much of the forest into grazing land although that trend is slowing or even reversing in a few instances. Because the MINK region is in a sensitive transition zone between the eastern U.S.

hardwood forests and the central prairies, forests in the region are vulnerable to a climate warming, especially if unaccompanied by increased precipitation. This is true not only of the areas where commercial forestry is practiced but also of the small forest holdings throughout the region that provide wildlife habitat, protect croplands from winds, and act as buffer strips protecting streams and wetlands.

Water Resources: The four MINK states do not comprise an independent hydrologic region. Because they include parts of four major water resource basins (the Missouri, Arkansas-White-Red, Upper and Lower Mississippi) the water available to MINK depends not only on events in MINK but also on circumstances in states located up river. Moreover, water use in MINK may be restricted by obligation to downstream states. Instream flow needs for navigation, fish, and wildlife habitat are large relative to withdrawal uses and mean streamflows.

Irrigation accounts for about half of the water withdrawal and 89 percent of the consumptive use of water within MINK. Nebraska and Kansas account for 97 percent of all irrigation water use within MINK. Groundwater provided 80 percent of all irrigation water and 48 percent of all water withdrawals in 1985. Intensive pumping and low recharge rates have resulted in the mining of water from the Ogallala formation underlying western Kansas and much of southwestern Nebraska. Conflicts over alternative uses of available water supplies have increased in recent years. Institutions for allocating water supplies within the region were stressed by drought during the 1980s and by a growing demand for more water for recreation and fish and wildlife habitat. Any climate change that tended to diminish runoff to rivers and reservoirs, reduced recharge of

groundwater where recharge is consequential or increased demand for water for irrigation or for competing uses could have profound effects on agriculture. Any reduction in instream flows might reduce the navigable period on the Missouri, could lead to a reduction in upstream hydropower generation, would undoubtedly complicate the problem of handling regional waste disposal in a manner consistent with maintaining water quality, and could diminish the significant economic value associated with water based recreation and the fish and wildlife resources of this region.

Energy: Climate change could alter both supply of and demand for energy in the MINK region. Little primary production of energy occurs within the region although large amounts of hydroelectricity are produced in the Upper Missouri Basin and a portion of this is consumed within MINK. Increased temperature and reduced precipitation diminishing surface water flows would reduce hydroelectric production and could interfere with the cooling of thermoelectric plants.

Demand for energy to power irrigation pumping would increase in a warmer, drier climate; demand for crop drying would diminish. Together, these uses account for less than 5 percent of the total energy used in the region. Heating and air conditioning account for 20 percent, and changes in climate would affect these uses. Overall, about 25 percent of the total current energy consumption in the region is climate sensitive.

5.2 Task B: Imposition of the Analog Climate on the MINK Region of Today

5.2.1 Modeling Approaches

In order to assess how climate change might affect a region's economy it is necessary first to establish its impact on the several sectors of which that economy is made and then to study the interacting effects of these impacts. A number of models were used to evaluate impacts on the individual sectors. For agriculture (primary crop production) we used the Erosion Productivity Impact Calculator (EPIC), a semi-empirical process model that simulates crop biomass and yield production, evapotranspiration

and irrigation requirement. The EPIC model, which is described in detail in Report IIB, was adapted to permit calculation of the direct effects of increased atmospheric CO₂ concentration on photosynthesis and evapotranspiration.

Over 50 farms were 'designed' after consultation with local agricultural experts in each of the four states to represent the wide range of agricultural systems used in the region. These farms differ in the soil type, crop rotation, and the management practices they use. EPIC simulations of current crop yields and water use were found in reasonable agreement with actual yields and water use when the current weather (1951-80 normals) and current CO₂ concentration were used as inputs to the model.

This being so, it was then possible to run the model on all of the representative farms under the four conditions of the B scenario--climate change only (B₁), climate change plus increased CO₂ (from 350 to 450 ppm) (B₂), climate change with simple response adjustments (B_{3.1}), and climate change with CO₂ and the same adjustments (B_{3.2}).

For forests we used a model known as FORENA to predict changes in biomass and species composition after imposition of the analog climate without and with the CO₂ increment and without and with adaptations. Details of the modelling procedures and results are in Report III.

Changes in irrigation requirements were modeled by means of EPIC. Modelling changes in regional water supply was more difficult. Ideally we would have compared streamflow in the 1951-80 control period with that during the 1930s. However, flows in the basins, especially the Missouri Basin, today are affected by diversions, reservoirs, and consumptive use which did not exist in the 1930s. Most of the 12,000 reservoirs now in the MINK region did not exist in the 1930s.

Among the thousands of gauging stations in the region, we identified a small number where water flows appear to have been unaffected by human activities since the 1930s. We used the ratio of their 1930s to current flows as a proxy for extracting what natural streamflows would be like if the climate of the 1930s were to reoccur. Details of the modelling procedures and results are in Report IV.

Analysis of B scenario impacts in the energy sector draw on the modelling and interpretations from the other three sectors and on analysis of how heating and air conditioning requirements are affected by temperature. (Report V).

5.2.2 Major Findings of B Scenarios

Agriculture: According to the EPIC simulations dryland crop yields are reduced on average by 20-25 percent except for wheat. Wheat is barely affected in the B₁ scenario. Higher CO₂ in the B₂ scenario offsets yield losses because of increased photosynthesis and reduced evapotranspiration. Losses of yield are considerably smaller under irrigation in B₁ and are virtually eliminated by the CO₂ increase in B₂. Yields of irrigated wheat are greater in the analog climate than in the control. No adjustments were allowed in B₁ and B₂. Evapotranspiration increases on irrigated land by about 25 percent for summer crops and 10 percent for winter wheat.

These yield reductions would increase the costs of crop production, resulting in declines in crop output of \$2.7 billion in the B₁ scenario, a decline of 17.1 percent from 1984/87 average level of production. When allowance is made for the CO₂ enrichment effect on yields (the B₂ scenario), the decline in crop production is \$1.3 billion, or 8.4 percent.

In the B₃ scenarios simple and currently available adaptations such as earlier planting, longer season varieties, and changes in tillage to increase water conservation are induced by the climate change. Yield losses are smaller and in some cases in which CO₂ and the adaptations interact positively yields are greater than under the control climate.

With on-farm adaptations, and without allowance for the CO₂ enrichment effect, crop production declines \$1.9 billion (12.1%) from the 1984/87 average level of production. With on-farm adaptations and CO₂ enrichment the production decline is \$0.5 billion (3.3%). These changes in crop production take into account a decrease in irrigated acreage proportional to the increased evapotranspiration.

Forests: Forests in southeastern Missouri are very sensitive to climate warming in association with decreased precipitation. Ten years after imposition of the analog climate simulated biomass production is reduced by 7-20 percent with the most severe losses at the northern margins of the forest. After 200 years of the analog climate biomass production decreases to 25-60 percent of production under the current climate. Under such conditions commercial forestry would be found only in the southeastern Ozarks.

Elevated CO₂ (B₂ scenario) moderates the biomass losses and slows the decline of the southeastern forest. In the longer term, forests still decline with simulated biomass down by 20-50 percent depending on location.

Species composition is not greatly altered under the analog climate with or without CO₂, (B₁ and B₂). The forests remain dominated by oaks although the natural range of pines extends further to the north than before.

In the near-term, adaptations to the declining productivity of the forests in MINK under a permanent analog climate condition appear very limited. Simulations of various management strategies show them to be uneconomic under current conditions. Responses are more likely to be reactive such as salvage harvesting and early harvesting which could mitigate some of the potential short-term losses associated with rising tree mortality. Areas in central Missouri could become better suited to shortleaf pines, but their simulated yields do not seem sufficient to justify any large-scale expansion of plantations.

Water Resources: Water would be much scarcer within MINK under the 1931-40 analog climate. Average annual natural streamflows would decline to 72 percent of their 1951-80 averages for both the Missouri and Upper Mississippi Basins and 93 percent for the Arkansas Basin. EPIC indicates that irrigation water withdrawals rise (in B_1) about 39 percent in Nebraska and 14 percent in Kansas. For the four MINK states, total withdrawals increase 14 percent and consumptive use increases 23 percent. For purposes of the B_1 analysis EPIC was programmed to provide irrigation water on demand which implies that it is not a scarce resource. This, of course, is not so even today. The rise in irrigation water requirements implied is not likely to be realized because of several institutional and economic constraints.

Increases in irrigation requirement are tempered somewhat by the increased CO_2 in the B_2 scenarios. Total withdrawal would decline by 4 percent and consumptive use by 6 percent below B_1 levels. Despite this reduction in demand water remains scarce and often deficient relative to combined instream and offstream uses.

EPIC-model results suggest farmers might adapt by shifting to longer season varieties. Since these varieties consume more water, their adoption might involve a reduction in total area irrigated. Perhaps too conservatively in $B_{3.1}$ and $B_{3.2}$, we have not considered improvements in irrigation efficiency, or introduction of more water efficient varieties. These kinds of adaptations, which could be effected in a few years, are dealt with in a later stage of the analysis.

With the analog climate and current operating criteria for dams and reservoirs on the mainstem of the Missouri River, the navigation season would be sharply curtailed, hydroelectric power production would decline to about half its normal level, and water in storage would drop to less than half of the long-term average during 60 percent of the years. The value of water-based recreation in MINK could be significantly and negatively affected by reduced instream flows under the analog climate. Net national benefits of the system would be greatly increased by operating it to provide minimum winter and summer flows for water supplies of downstream communities and by increasing the size of the permanent pool to enhance hydropower and recreation benefits within the upper basin. Navigation needs would receive a lower priority than at present.

Energy: The energy implications of changes in irrigation demand in the B_1 case are for a 3-4 percent increase in agricultural energy consumption although some of this would be offset by a reduction in energy required for crop drying. Reduced streamflow could jeopardize hydroelectric operations within and outside of the region, and elevated temperatures could impair cooling water condensing operations at thermoelectric plants. Adaptations might involve improved irrigation efficiency to save energy as well as water, recourse to marginal cost pricing for electricity to encourage conservation (although higher

temperature might dictate the need for some additional generating capacity to meet MINK air conditioning demand), and modernization of cooling methods at thermoelectric facilities.

5.2.3. Implications for the Regional Economy

The economy-wide impact of the analog climate would, in the short term, come mainly way of agriculture and water resources. Crop production in MINK draws on a wide range of services provided by manufacturers and vendors in the region, for example fertilizer, pesticides, farm machinery, financial services, and so on. In addition, cattle and hog production in MINK is dependent on locally produced feedgrains (corn and sorghum) and the region's important meat packing industry is dependent on locally produced cattle and hogs.

These linkages between crop production and other sectors of the regional economy--called crop production multipliers--indicate that the decline in crop production in the B scenarios would have repercussions on regional production as a whole. We estimated these economy-wide effects with IMPLAN, a regional input-output model developed by the U.S. Forest Service. We made two sets of such estimates. For one set we assumed that regional exports of the crops would fall by the amount of the fall in crop production, reflecting the region's loss of external markets because of higher crop production costs. The supply of feedgrains to local animal producers would be unaffected, so the only feedback, or multiplier, effect of the decline in crop production is on activities directly and indirectly linked to crop production as suppliers of inputs. In the worst case B₁ scenario (no CO₂ fertilization effect and no on-farm adjustments) the \$2.7 billion decline in crop production and exports would induce an additional production decline of \$1.4 billion in industries linked as suppliers to

crop production. The total production decline of \$4.1 billion would be 1.3 percent of total MINK production of \$309 billion in 1982.

In the best case scenario (with CO₂ enrichment and on-farm adjustments) the \$500 million decline in crop production and exports would reduce total regional production by \$910 million, or 0.3 percent.

Should the decline in crop production fall not on exports but on regional users of grain--primarily animal producers in MINK--then the feedback effect on the rest of the economy would be more severe. The impacts would reflect not only the effects on industries directly and indirectly supplying crop production but also the effects on animal production, and therefore on meat packing. In the worst case scenario the decline in crop production would induce a decline in total regional production of \$29.9 billion, or 9.7 percent. When allowance is made for CO₂ enrichment and on-farm adjustment effects on crop production the decline in total regional production is \$17.6 billion, or 5.7 percent.

The assumption that all of the decline in crop production would fall on regional users of grain is unrealistic because MINK producers of animals would be able to import feedgrains from other regions. The regional production effects of the decline in crop production, therefore, would be less than the estimated 9.7 to 5.7 percent.

Water resources impacts, apart from irrigation, are less clear, but might be comparable to agricultural impacts. Although good estimates of the size of the water-based recreational industry in the region are not available, evidence suggests that it is large. Should the industry decline under the weight of the analog climate, the regional economy as a whole could be significantly affected.

Whether these possible declines in regional income would be permanent would depend on whether the labor and other resources released by the production declines would find employment elsewhere in the MINK economy. To the extent that they do, the income decline would be less, although the overall pattern of regional output would change somewhat.

5.3 Task C: The Future Baseline

Agriculture: Projections of the U.S. Department of Commerce's Bureau of Economic Analysis indicate that real income in MINK would grow about 75 percent from the 1984/87 baseline to the 2030 baseline. Our projections of the region's agriculture, taking account of the growth of global markets for grains and soybeans, of the nation's share in these markets, and MINK's shares in national grain and sorghum production, indicate an increase in the region's crop production between the two baselines of about 67 percent.

Using EPIC, we projected crop yields in the MINK region in the absence of climate change to be about two-thirds higher than in the 1984/87 baseline, and evapotranspiration to be about 4 percent less. These yield increases are bred into the plants by hastening leaf development and increasing photosynthetic efficiency, harvest index (portion of the total biomass in harvestable organs), and pest resistance. Mechanical improvements in harvest efficiency also contribute to the yield increase.

Forests: Trends in the forest industry suggest that in 2030 in the absence of climate change real prices of forest resources will be relatively stable and wood supplies will be adequate. More forests will have commercial uses as technology develops yield-enhancing, wood-saving and wood-extending methods. Wood-extending technologies might open markets for the low valued wood of Missouri, but the difficult terrain of the Ozarks makes plantation forestry unlikely in the region.

In a prosperous America, recreation uses of the existing Missouri forestlands would gradually supplant much of its agricultural and industrial uses. In an energy scarce America, the Ozark forest might be increasingly used as a source of renewable biomass for energy. The

potential has been demonstrated in the region for high yield, short rotation plantations that can produce a supply of biomass. However, unless energy prices are sharply higher than currently expected for 2030, the economy will not support biomass plantations on lands that can support agriculture.

Water Resources: Water supplies available to MINK in the year 2030 will be less than today even in the absence of climate change because of depletion of groundwater stocks and increased instream use. Depletion of groundwater in western Nebraska and Kansas would sharply reduce irrigation in these areas. Surface sources could also decrease if irrigation is expanded in the Upper Missouri Basin as authorized by Congress in the Pick-Sloan plan. Growing concerns over instream flows are likely to minimize such an expansion, however. Conservation measures should be sufficient to offset population-driven growth in demand so that consumptive use for non-irrigation purposes would remain roughly unchanged. Instream flows of water in MINK should be about the same as in the 1980s baseline unless big water diversion projects are built on the Upper Missouri River. Under these circumstances, water-based recreation appears likely to continue to grow in relative economic importance.

Energy: Energy consumption is projected to grow in the MINK region at an annual rate of 0.25 percent. Economic growth is projected at about 1.2 percent. The implied improvement in the region's energy intensity continues a trend established in the 1970s in response to rising real energy prices. Technological improvements in energy utilization will also contribute to decreased energy intensity. Agriculture will participate in the trend to declining energy intensity as it has in the past.

No drastic shift in the mix of energy sources and forms is projected for the region. Electricity is growing faster in MINK than other forms of energy and will continue to do so. A modest expansion of the region's generating capacity would assure adequate supplies. Expansion will involve

new thermoelectric plants. Hydropower cannot expand significantly in the Missouri River Basin. The MINK region could become a major energy provider (for itself or for export to other regions) only by way of biomass fuels. A set of economic conditions and/or environmental policies not currently apparent would be required for this to happen.

5.4 Task D: Imposition of the Analog Climate on the MINK Region of 2030

5.4.1 Major Findings of the D Scenarios

Agriculture: Despite the greater productive potential assumed to be bred into the crop plants of 2030, they remain sensitive to the imposition of the analog climate. For all crops but wheat yield reductions in the D_1 (analog climate) and D_2 (analog climate plus CO_2) cases are similar, in percentage terms, to those that occur in B_1 and B_2 . Absolute losses are higher in D_1 and D_2 , but yields nonetheless remain well above the Task A (current) level.

The virtually costless farm-level adjustments used in the B_3 scenario have a similar effect in reducing yield losses when applied in the D_3 scenario. In the D_3 scenario, however, two additional adjustments are tested as responses to the emerging climate change. These are reduced stomatal conductance as a surrogate for drought resistance and improved irrigation efficiency. When applied in the $D_{3.1}$ and $D_{3.2}$ cases yields increase significantly.

The combination of adjustments plus higher CO_2 in Task $D_{3.2}$ raises all crop yields above the Task C (future baseline without climate change) level, except for corn which remains only 7 percent below that level. The

yields of irrigated and cool season crops benefit more, overall, than do the warm season crops.

In the worst case D scenario (no CO₂ enrichment effect and no on-farm adjustments) production of corn, sorghum, wheat and soybean in the region declines \$5.3 billion--22 percent--from the baseline projection for 2030. In the best case D scenario--CO₂ enrichment and on-farm adjustments--only corn production declines. Because of favorable effects of CO₂ and on-farm adjustments on yields of sorghum, wheat and soybeans, production of these crops rises under the analog climate, and total production of the four crops increases \$645 million, or 3 percent from the 2030 baseline level.

Forestry: Even in the 2030s when demand will be different and technological options greater, our projections for the MINK region show a long-term decline in both inventory and harvest under the analog climate. Some, but not all, of this decline is offset by a rising CO₂ level. The forest decline might set in motion a temporary increase in forest activity in the form of salvage logging. In the long-term, forestry would decline and shrubs and grasses would replace the forest in many places.

Large carbon taxes causing a shift to renewables might lead to wood-fired electrical power plants in the more forested Ozarks. In this case, along with more rapid harvesting in the Ozarks, some short-rotation plantation forest management might be justified.

Water Resources: The imposition of the analog climate on the MINK region of 2030 would sharply reduce instream flows. The hotter, drier climate would improve the net profitability of irrigated relative to dryland agriculture in parts of the MINK region, but water supplies would pose a greater constraint to expansion of irrigation. As a result of these

two offsetting factors irrigated acreage in Iowa and Missouri could grow at about the same rate (3.7 percent/annum) with or without climate change.

Groundwater recharge would be lower under the analog climate.

Irrigation in the High Plains of Nebraska and Kansas, which should be keyed to renewable supplies by 2030, would necessarily be lower under the analog climate. The anticipated reduction in instream flows under the analog climate is likely to force a contraction in the region's water-based recreation industry.

Energy: We speculate that the analog climate in 2030 might increase agricultural energy demand by about 3 percent. Elsewhere in the economy, higher cooling costs will be offset, at least partially, by lower heating costs. The climate change implications for energy in MINK are relatively minor. Given a forty-year time horizon with the expectation that climate will change gradually rather than precipitously allows for exploitation of numerous adaptation opportunities. Investments in, and practice of, energy conservation can be stimulated to greater levels because of changing climate than they would otherwise be in 2030. Improved efficiency in irrigation pumping would be particularly important because of the increased demand for irrigation and the stringency of water supply even in the absence of warming. Utilities forced to expand capacity and improve generation operations will have ample time to consider climate change in long-term planning strategies and to take advantage of existing and prospective technological opportunities.

5.4.2 Implications for the Regional Economy

The changes in crop production in the D scenarios would surely have repercussions throughout the regional economy, depending on the size of the crop production multipliers reflecting the linkages between crop production and other industries. These multipliers depend on technical and economic

conditions that will determine MINK's economic structure in 2030. We were unable to explore these conditions, but something useful can nonetheless be said about regional economic impacts of the D scenarios. The analysis of the B scenarios showed that if all of the decline in crop production were reflected in reduced exports, the effect would be to reduce total regional production by roughly 0.3 to 1.3 percent. Noting this, and allowing for the growth of the MINK economy to 2030 (75% from the 1980s baseline according to the Bureau of Economic Analysis projections) suggests that even if the crop production multipliers were to double from the current to the 2030 baseline, the decline in crop production in the worst case D scenario would have a small percentage impact on the regional economy, if, that is, all the decline occurred in crop exports.

However, if the decline in crop production resulted in an equal reduction of feedgrain supplies to animal producers in MINK, and if the crop production multipliers were to increase, then the analysis of the B scenarios suggests that the worst case D scenario would imply a decline in total regional production of more than 10 percent--no longer a trivial amount. This worst case result for the economy as a whole probably is less likely than the best case result, for the same reason as in the B scenario: the decline in crop production is more likely to show up as reduced exports than as reduced feedgrain supplies to local animal producers.

The worst case result in the D scenarios also assumes that animal production in MINK remains closely related to feedgrain production, and that the animal-meat packing relation remains important. The high multiplier effect of the decline in crop production in the worst case result for the regional economy assumes continuation of the strong

locational relationship in MINK between feedgrain production, animals and meat packing.

Of course if crop production in MINK should increase, as in the D₃ scenario with the CO₂ effect and on-farm adjustments, then the impact of the analog climate on the regional economy would be positive, at least so far as agriculture is concerned.

The economy-wide impacts of the analog climate on irrigation water are indirectly captured by way of the modelled agriculture production. However, other uses of water, both instream and offstream, could be adversely affected. It appears likely that the value of water-based recreation in MINK would be significantly and negatively affected by reduced instream flows under the analog climate. However, because of the small role that water-based recreation plays in the overall regional economy, the economy-wide impact of the analog climate on recreation would be relatively minor. Our rough estimates suggest that a value of water-based recreation of not more than \$2-3 billion or 0.6-1.0 percent of total regional output in 1982. Thus, even with high multiplier effects, a 25-30% reduction in the industry under the analog climate would have a small impact on the economy as a whole. The analog climate might reduce total regional income at most 1 or 2 percent by way of the surface water resource.

As in the B scenarios, the permanence of the climate-induced changes in regional income would depend on the success of resources released by the changes in finding employment elsewhere in the region.

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6. General Methodological Issues

The MINK project aimed primarily at the development of a workable methodology for producing policy-relevant assessments of the regional-scale

impacts of climate change and of the opportunities for response and adjustment to such impacts. The methodology developed provides a way to produce such assessments not so much for the world as it is today but rather for such a time in the future when the climate change may actually be occurring. Of course, predictions of climatic changes (driven by greenhouse warming or by other causes) cannot yet be made on the regional scale. It must be clear, therefore, that no methodology, however perfect (and our's is certainly not that), can do more at this stage than help alert the policy-maker to the nature of a region's current and future physical and economic vulnerabilities and its potential for coping with climate change.

In the following pages of this paper we explore the general strengths and weaknesses of our methodology--probably not ourselves recognizing all of either. Strengths and weaknesses of the methodologies we have used in the individual sectoral analyses are discussed in the appropriate working papers.

Perhaps the most unique element of the MINK project lies in its forward-looking methodological approach. Building on a solid understanding of the region's current structure and economy we project--cautiously--what the region may be like in the future at such a time as the climatic changes that concern us may actually be felt. The question of how today's world would behave were climate to change in a particular way is interesting but it is not the relevant question. We attempt to provide guidance as to how the world would behave at such a time as the climate does change.

How to select and define regions for study is another important methodological question. We chose the MINK region because of its relatively heavy reliance on climate sensitive natural resources and industries and because of its relatively uncomplicated physiography and economy. The working papers reveal, however, that the MINK region is not

as uncomplicated as we had thought. The region's reliance on streamflow that originates well outside its borders and its economic sensitivity to national and international markets for grains and soybeans are cases in point. We learned, too, that intellectual limits are imposed when regions are defined by political boundaries but, similarly, when they are defined by physiographic boundaries--river basins, for example--the analyses may be constrained in other ways.

In this first test of our methodological design we choose to use a relevant portion of the climatic record as our "analog scenario" of climate change. The choice, we feel, was appropriate for the MINK region because the analog--the climate of the 1930s--is consistent, at least in direction, with expectations of climate change for the region in the train of greenhouse warming. By using real weather records we had an opportunity to explore the variability of climate change impacts in time and in space in a way that cannot be done when current climate is altered by some fixed changes in temperature and precipitation. But complexity, of course, comes at a considerable cost in time and resources.

It is also important to point out that the popular image of the 1930s is based on its worst years, 1934 and 1936. Not every year in that decade was droughty and not every place within the MINK region was affected equally. For this reason our results are less catastrophic than might have been anticipated. On the other hand, it seems reasonable to believe that if greenhouse warming changes climate, those changes will not be expressed in exactly the same way in each year and each place. Hence our 'scenario' of climate change based on an actual hot and dry decade is probably more useful than scenarios in which more uniform changes in time and space are imposed.

The MINK methodology does not, however, depend on the use of analog climate scenarios. Scenarios derived in other ways can be accommodated.

Climate inversion techniques to generate intra-grid box variability from GCM output and knowledge of real regional climatic relationships may prove useful in coming years. There is hope as well that the GCMs, because of smaller grids and improved parameterization, may themselves begin to provide more credible predictions of regional climate changes than they now do. Weather records from which to choose climate analogs may not be satisfactory for certain regions of the world in which we are interested. Even where such records do exist, they may contain no periods that are consistent either in sign or magnitude with expectations for regional climate change. Possibly pseudo-analog climate scenarios can be synthesized from individual months or years in the record.

Focussing on the impact of climate change on the regional economy as a whole is, we believe, a novel methodological feature of our research. Our task in dealing with these impacts was greatly facilitated by having available the IMPLAN input-output model for application to the MINK economy. Such models are specifically designed for regional impact analysis. They permit the calculation of the "multiplier-effects" of production changes in any particular sector on all other sectors of the economy. Of course such models are no better than the data underlying them and the skill with which they are put together. Moreover, the models are more useful for studying impacts of changes in current conditions than they are for analysis of conditions in the more distant future. This is particularly relevant to the study of climate change impacts since those impacts are likely to be felt only some decades hence. We sought to deal with this limitation not by projecting IMPLAN into the future--an immensely complicated undertaking--but by engaging in a kind of sensitivity analysis. We first used IMPLAN to estimate the impacts of the analog climate under current conditions. Then we asked how different would the multipliers have

to be in the 2030 baseline situation for the economy-wide impacts of the analog climate to be much different, in percentage terms, than they would be in the current baseline situation. One can then address the question, how likely is it that the multipliers will change enough to make a significant difference in the climate change impacts in the future compared with the present. In the case of MINK we found that the multipliers would have to change substantially because the region-wide impacts of climate change in the current situation--at least those transmitted through agriculture--would be small: from a 1 percent to at most a 10 percent change in total regional production, with the lower estimate more likely than the higher one.

7. A Final Scorecard: Impacts, Possible Adjustments, and Policy Issues

Agriculture: For agriculture our simulations show that were the climate of the 1930s to recur in 2030, crop yields in the MINK region would decline by from 10 to 25 percent in the absence of adjustments. Plant requirements for irrigation water would increase by about 20 percent but water supplies would decline because of reduced streamflow and reduced groundwater recharge. There would be little direct effect on animal production, but reductions in range carrying capacity and indirect effects through higher costs of feed could be important.

Adjustment opportunities will be available for dryland farming. Some readily available and inexpensive adaptations might include earlier planting, use of longer season varieties, and conservation tillage to improve soil moisture conditions. Switching from more to less heat and drought sensitive crops will also be possible. The perception or conviction that climate is or will be changing will trigger or hasten the development of other adaptive techniques. Plants may be bred specifically for greater heat and/or drought resistance, for example. Irrigation

agriculture will be adapted in a number of ways. The decrease with time of irrigation already foreseeable for the High Plains will be accelerated if the 1930s climate returns and becomes the new norm. This will prompt a return to dryland agriculture which may be facilitated by the development of new and/or hardier crops. Irrigation will become economically attractive for areas whose water resources are adequate and not yet used for that purpose. Such areas exist in the eastern portions of Nebraska and Kansas and western Iowa and Missouri. The prospect of a hotter, drier climate will stimulate research and investment in improved irrigation efficiency. Animal production will, likely, move to where the grain is. However, our results suggest that, after adaptive responses, local losses in feedgrain production, should they occur, would be small and readily compensated by imports from regions that become relatively more productive. Moreover, reduced grain supplies likely would prompt additional research on ways to improve weight-gain to feedgrain ratios.

There are policy issues to be addressed if development of the kinds of adaptations described above is to be facilitated. Changes in support pricing structures, desirable on other grounds, can encourage more flexible cropping responses by dryland farmers. Changes may be advisable in state water law and federal taxation policies to impart greater flexibility to management of irrigation water. Research institutions need to be maintained and managed so as to be able to respond to emerging signs of climate stress.

Forestry: The 1930s climate, were it to become the new normal, would affect forestry quite adversely in the MINK region. Production of timber on forest land would decline and mortality would increase, leaving the local forest products industry with declining local supplies of high quality timber.

Under foreseeable economic circumstances, adjustment opportunities in the existing forests are limited. The rugged terrain and low productivity of the forested Ozarks region result in high costs and low returns to management. Faced with dead or declining trees, private woodland operators in this region would begin salvage harvesting and would, in general, accelerate harvest temporarily. Ultimately, the forest products industry of the Ozarks region would have to close plants and relocate to areas that are favored, relatively, by climate change. However, new wood processing methods that require lower quality stock may allow the industry to persist in the region.

Forest activity could expand modestly into areas of marginal farm land. The better soils and flatter terrain to the north and west of the Ozarks region make plantation forestry more practical there. Plantations of high-valued black walnut should remain feasible under a moderately warmer climate. However, the scale of such plantations should remain very small relative to the current acreage in forests, with any great increase driving down prices for walnut and requiring the use of more costly land. A large-scale expansion of forests into the plains would be conceivable only if the demand for wood as a biomass substitute for fossil fuels increases to the extent that short-rotation biomass forestry could become profitable.

Governmental intervention might be required to cope with the increased risk of fire in the Missouri forests and to compensate for the loss of recreational potential and other forest amenities. Subsidies for replanting or for research on forest plantation management for biomass production might be required. The forest products industry might be prompted to increase investment in wood processing technologies to utilize lower-quality growth or to support short rotation forestry for biomass production.

Water Resources: As has been pointed out above, a return to the 1930s climate would decrease surface water supplies available for irrigation and accelerate the decline in groundwater stocks in the High Plains. Municipal and industrial water users might experience periodic shortfalls in supply. Water quality would be threatened as more people and economic activity increase waste discharges to the region's diminished flow of surface water. The reduced quality and quantity of surface water would threaten major losses of fish and wildlife where their support is the primary residual use of water. Little hydropower is now generated within the MINK region. However, major declines would occur in hydropower production in the upper reaches of the Missouri basin, affecting the cost of hydropower imported into the region. Water-based recreation opportunities would diminish. The navigation season, especially on the Missouri River, would be severely curtailed.

Impacts on and responses to climate change in the irrigation sector have been dealt with in the section on Agriculture. There are various adaptations that might be made through dam operations to deal with stresses imposed on municipal and industrial water uses, hydropower generation, fish and wildlife and recreational requirements, but priorities will have to be established among these uses. Reallocation of water from agriculture can also provide some relief for the aforementioned uses. Shortfalls in hydropower can be made up in part by the employment of alternative but more expensive power sources. Shortfalls in navigation opportunity can be partially offset by the development of lower-draft vessels. Rail and highway transport can be expanded to accommodate losses in river navigation opportunity.

Policy issues must be resolved if appropriate adjustments to climate change impacts on water resources are to be made. Obstacles to realistic water pricing and marketing must be removed if transfer of water from agriculture to other uses is to be facilitated. Regulation will be required if groundwater is to be pumped at sustainable rates.

Energy: Should the climate of the 1930s become the new norm, the MINK region's demand for energy would increase modestly because of higher irrigation requirements. However, this would be offset somewhat by decreased crop drying requirements. Some increase in air conditioning demand would occur, offset somewhat by decreased space heating. The increase in air conditioning would, however, increase peak load requirements. Expansion of hydropower capacity would be limited by reduced water supply. Reduced river flows and higher water temperatures would increase the difficulty and the cost of cooling in thermo-electric plants. If enterprises are developed to raise biomass for substitution of fossil fuels, production potential will be reduced by the prevalence of a change of climate to hotter and drier.

The increased demands for energy to pump irrigation water could be offset by improvements in both irrigation and pumping efficiency. Similarly, the increased energy requirement for power plant cooling could be offset by end-use improvements in cooling technologies. Increased demand on thermo-electric plants, especially for peak load air conditioning requirements, can be accommodated partially by enhanced electric conversion efficiency. Dry cooling towers can compensate for the plant-cooling capacity lost as a result of reduced streamflow and higher water temperatures. Improved agronomic and forestry management techniques and

adaptations can be applied to offset the negative effects of the analog climate change on biomass production.

Facilitating adaptations to the impacts of a climate change on the energy economy of the MINK region will require policies that strengthen energy conservation programs in agricultural, municipal, industrial, and residential uses. Rational utility pricing practices can provide incentives for conservation and disincentives for waste. Since non-hydropower facilities will be needed to make up for the loss of imported hydropower and the increase in demand for energy, research and development efforts would be targeted at improvements of thermo-electric cooling technologies. The economic feasibility and environmental soundness of biomass production for the region has yet to be demonstrated. Research will be required before these questions can be resolved.

8. Conclusions

We conclude on the basis of our analyses that in the MINK region of 2030 with a climate like that of the 1930s:

- *The impacts on agriculture overall would be small given adaptation, but at the margins losses could be considerable --e.g., a shift in irrigation from west to east.
- *Although by 2030 the impacts on forestry would not be fully felt in the long term, they would be severe. There is little potential for adaptation to the climate change unless the production of wood for biomass fuel makes adaptation economically justified. However, forestry is a very small part of the MINK economy.

*Impacts on water resources would be major and severe. The quality and quantity of surface water would diminish. Water-based recreation would suffer losses and navigation would become uneconomic on the Missouri. Rising instream values would make agriculture less competitive for surface water and declining groundwater supplies would hasten the abandonment of irrigation in the western portions of the region.

*Unless the climate-induced decline in feedgrain production falls entirely on animal producers in MINK, the regional economic impacts of the climate change would be small, especially after adjustments, because agriculture and the other natural resource sectors are a small part of the regional economy. It is unlikely that the decline in feedgrain production would fall entirely on animal producers because they would be able to substitute imported grain for local production.

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