ENERGY AND ENVIRONMENTAL ANALYSIS, INC.

Documentation of World Oil Logistic Model (WOLM)

Submitted to:
BNL
In support of
Energy Information Administration

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ABBREVIATIONS

BBL = Barrels
Bbbl = Billion Barrels
EEA = Energy and Environmental Analysis, Inc. (an Arlington, VA consulting company)
EIA = the U.S. Department of Energy's Energy Information Administration
IEA = International Energy Agency (Paris, France)
IEO = EIA's International Energy Outlook
Kbbl = Thousand Barrels
MMbbl = Million Barrels
SAGE = EIA's SAGE model
USGS = United States Geological Survey
WOLM = World Oil Logistic Model

1 EXECUTIVE SUMMARY

This document describes a world oil production forecasting model (WOLM) that was developed by EEA for EIA in support of the SAGE model. WOLM is an Excel spreadsheet that allows the user to generate forecasts of future oil production using a modified “Hubbert” or “Logistic” equation. File layout, operation, methodology, and data sources are documented. All of the data, formulas, and source code reside within a single Excel file. This documentation also describes how the data and equations from WOLM can be implemented within the SAGE model to forecast oil production for non-OPEC regions.

1.1 World Oil Logistic Model (WOLM)

The World Oil Logistic Model is an Excel spreadsheet model that takes long-run crude oil supply curves (from EEA’s WAU model discussed below) plus historical production and reserve data and produces a forecast of annual crude oil production to 2100 by country as a function of oil price. The model is based on a "Hubbert" or "Logistic" curve concept but modifies that concept to account for the crude oil supply curve economics and how the price of oil could affect the "shape" of the curve (that is, higher oil price will accelerate oil exploration and skew the Hubbert production curve to the left.) The model also calculates reserves, reserve additions, new oil wells drilled and the number of operating oil wells as additional outputs.

1.2 World Assessment Unit (WAU) Model

The WAU model takes inputs of 1) USGS resource base, 2) factor cost for drilling, well operation etc. and 3) financial assumptions and produces the costs of incremental resources. For crude oil this is $/bbl for each additional million barrels of proven reserves. The WAU is an Excel spreadsheet model created by EEA that can be described as a:

- **Resource base analysis model** that produces full, adjusted field size distributions and resource amount (crude oil, gas, NGLs) by assessment unit (play) and country.
- **Discovery process model** that describes the way in which the undiscovered fields will be found during future increments of exploratory drilling.
- **Discounted cash flow model** that calculates a simple DCF for each increment of drilling and the resource cost of oil ($/bbl) for that increment
- **Long run supply curve generating model** whose ultimate output is the cost of finding, developing and producing each additional increment of crude oil.

1.3 Modifications to SAGE

The intent behind building the World Oil Logistic Model is to test out data and algorithms that could be used in SAGE to represent oil production for non-OPEC regions. The World Oil Logistic Model was built at a country level because there are differences in the amount and quality of the data for each country. The country-level structure in the model will allow the underlying data to be kept in its original format and will permit aggregations into regions using current (or possible future changes to) SAGE region definitions. We expect that the SAGE implementation will be at the region level and have provided for a way to aggregate the country-level data into initial (that is, values for the base year) regional input parameters for SAGE.

The proposed working concept of how this could be implemented into SAGE is that a preprocessor called within SAGE would take initial parameters (and then results from each run period) and estimate cumulative production for each region and the last period's production rate. Based on those parameters the preprocessor would calculate all the needed coefficients to estimate production in the current SAGE period as a function of oil price.

Because the relationships are nonlinear there is no practical way to put them directly into the SAGE solution process. For this reason, we assume that the preprocessor would create "supply steps" for million barrels per day of production at say, 20, 25, 30, 35, 40, etc. dollars per barrel for each model forecast period. The SAGE model would then solve for conventional oil production in non-OPEC regions using that period's supply curve. Based on period X results, the preprocessor would then set up the curves for period X+1 and so on for each of SAGE's five-year forecast periods.

2 REPORTING CONVENTIONS

2.1 Liquids Reporting Basis

The historical and forecast liquids reported in this model are the sum of conventional crude oil and lease condensate, as per EIA's requirements for SAGE modeling. These two wellhead liquids streams (crude oil and lease condensate) are reported together in the available data. All volumes titled "NGLs", whether labeled "plant liquids" or just "NGLs", are currently excluded. A structure is included that allows the user to adjust the cumulative production, growth, and undiscovered resource by specifying a percentage of NGLs to classify as condensate. Unconventional liquids such as oil sands, synthetic oil, gas to liquids, coal to liquids, and ethanol are excluded. Refinery gain volumes are also excluded.

Care should be taken when comparing forecasts of crude oil plus condensate from the WOLM to the production forecast presented in the International Energy Outlook (IEO) Table E4. "World Oil Production by Region and Country, Reference Case, 1990-2025". The IEO data contain plant NGLs and refinery gain volumes. The WOLM worksheet TabE4 presents the various data series for comparison.

2.2 Years

Historical data begin in 1980, the first year of the EIA annual production tables from the International Energy Annual. The various historical input data sheets are dimensioned to 2010. Please see the data sources section for additional information about annual data.

2.3 Units

The original data are reported in various units. Annual production is reported in thousand barrels per day (Kbbl/day). Cumulative production, reserve growth, and new fields undiscovered volumes are reported in million barrels (MMbbl). Reserves are reported in billion barrels (Bbbl).

WOLM scales all input data to units of billion barrels (Bbbl) and produces a forecast with units of billion barrels per year.

2.4 Countries

The WOLM forecasts annual oil production for 116 countries that have historical production or USGS undiscovered resource estimates. An important part of WOLM is a lookup table that cross-walks reported and standard country names. Each source worksheet contains a standard country name in column A. The standardization of country names allows the use of lookup functions to easily combine information from multiple input sources.

The countries of the world changed with the breakup of the Soviet Union in the 1990s. Historical data are not available at the individual country level for the Former Soviet Union prior to 1992. A "Soviet Bloc Historical Data" category was added to carry the pre-1992 historical data through to the OUTPUT worksheet -- NO FORECAST IS PRODUCED FOR THIS CATEGORY.

3 METHODOLOGY

3.1 Introduction

The goal of this project was to develop a methodology for preparing data and algorithms to be used in SAGE to forecast non-OPEC conventional crude oil production. According to EIA, the methodology must be readily understandable, the input data traceable and verifiable and the process of updating the data and model should be unburdensome.

Before getting this assignment from EIA, EEA had already created the World Assessment Unit (WAU) model to estimate the resource cost of undiscovered oil and gas around the world. After starting this project, we decided that the WAU should be the basis for the economic evaluations and "supply curves" going into SAGE since the WAU methodology was deemed by us to be good and the modest EIA budget for this project precluded any major new effort at model or data development.

The major development issue, therefore, was how to translate the resource cost curves into production period for a SAGE forecast horizon that can span several decades. We chose a modified version of the "Hubbert" or "Logistic" curve to do this since such curves are widely known used to estimate future levels of crude oil production. The suggested methodology modifies the Hubbert curve concept to:

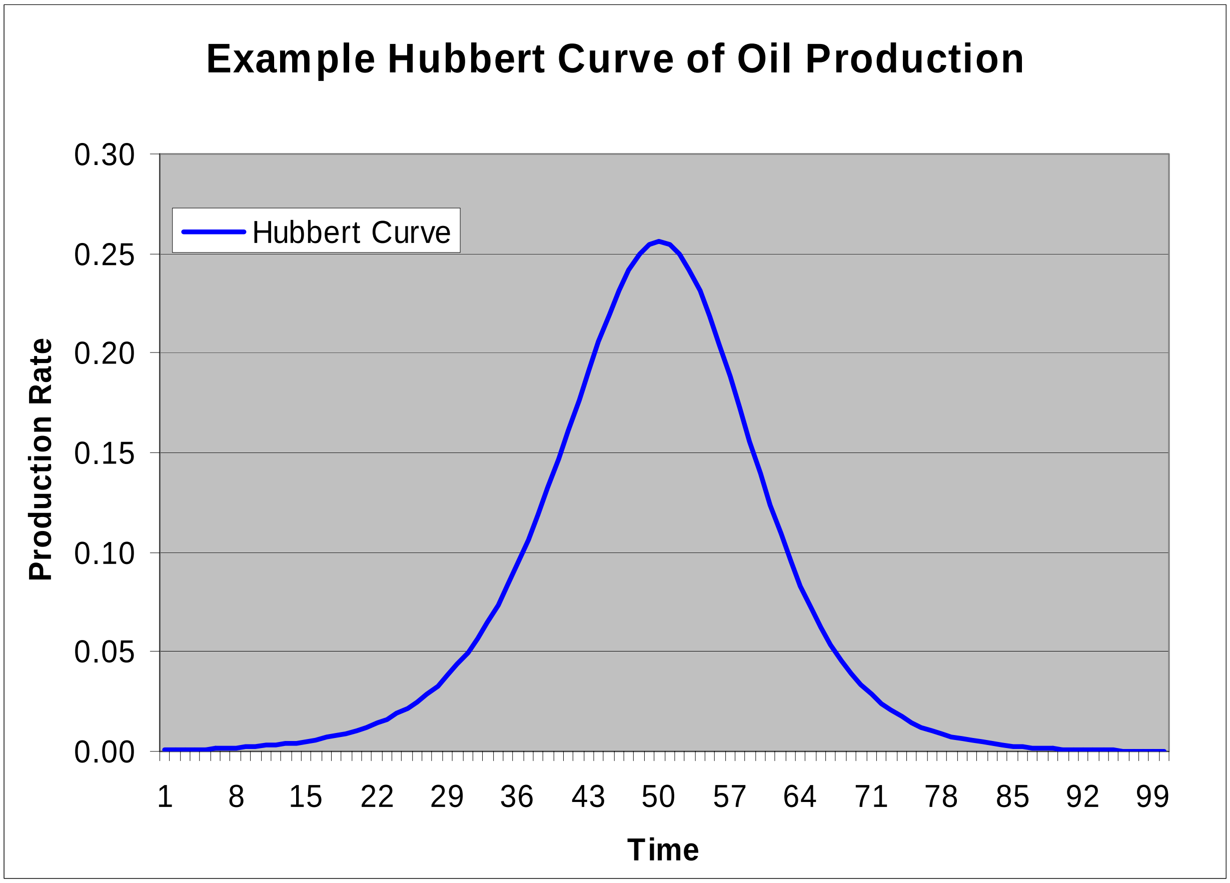
1) Account for the crude oil supply curve economics as a function of the underlying resource base, price of oil and upstream technology, and
2) Allow changes to the "shape" of the curve (that is, higher oil price may accelerate oil exploration and skew the Hubbert production curve to the left.)

Stated in other words, the WAU would be used to estimate the economic resource size (the area under the production curve) while a modified Hubbert curve would be used to determine the shape of the production curve over time.

3.2 The Hubbert or Logistic Curve

The geophysicist M. King Hubbert created a mathematical model of petroleum extraction which predicted that the total amount of oil extracted over time would follow a logistic curve. This implies that the predicted rate of oil extraction at any given time would then be given by the rate of change of the logistic curve. With time on the X-axis, a graph of production follows a bell-shaped curve with a peak production level reached when cumulative production is equal to half of the resource base. In 1956, Hubbert predicted oil production in the continental United States would peak in the early 1970s, which indeed it did. According to Hubbert's model, U.S. oil reserves would be exhausted before the end of the 21st century.

Figure 3-1 Example of Hubbert Curve



Given past oil production data and barring extraneous factors such as lack of demand, the Hubbert model can be used predicts the date of maximum oil production output for a region, a country or the entire world. The early part of the cycle can be referred to as the "growth period." The maximum output point is referred to as the "peak." The period after the peak is often referred to as the "depletion period." (See Figure 3-1)

<u>Equations for Hubbert Curve</u>

The mathematical representation of the Hubbert or logistic curve can be written in many forms. Probably the easiest to understand format is the linear relationship associating production (Prod), and cumulative production (Cum):

Prod/Cum = Intercept + Slope(Cum)

Slope is a negative number so Prod/Cum is downward sloping straight line. This equation also can be written as:

$$\textbf{Prod} = \textbf{Intercept(Cum)} + \textbf{Slope}(\textbf{Cum}^2)$$

An important aspect of Hubbert curve is that the area under the production curve represents the resource base (RB). This relationship can be expressed as:

$$\textbf{RB} = \textbf{-Intercept/Slope}$$

In the original Hubbert specification the resource base is a fixed quantity that does not change over time. However, in the suggested SAGE methodology, the area under the production curve is defined as the economic resource base, which is represented as a function on oil price and technology. In the suggested SAGE methodology, the intercept and slope parameters of the production equation are adjusted each forecast period based on any changes to the economic resource base. The two mathematical relationships that can be useful in setting up Hubbert function parameters from historical production data and an economic resource base estimate are:

$$\textbf{Slope} = \textbf{(Prod/Cum) / (Cum-RB)}$$
$$\textbf{Intercept} = \textbf{-Slope(RB)}$$

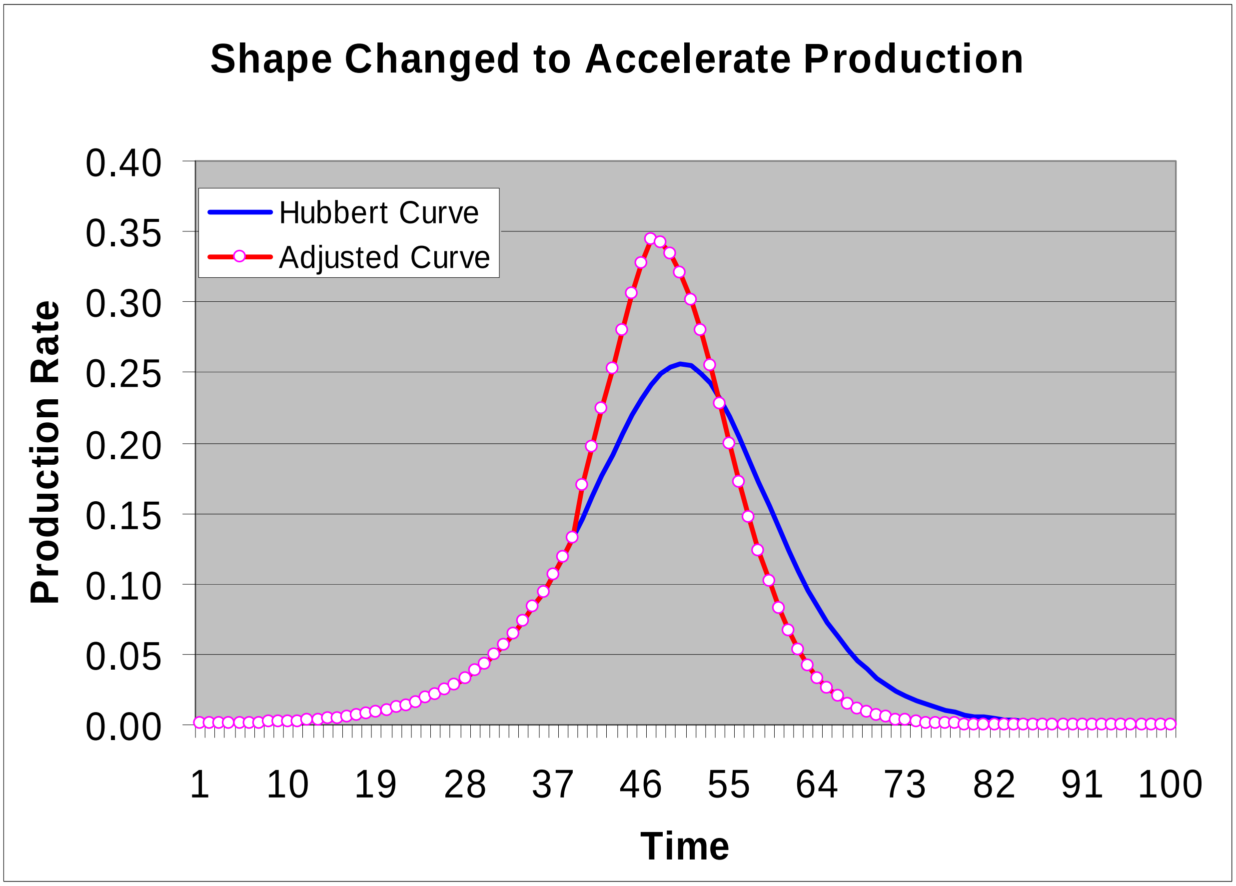
Because the parameters will be changing with time and the values must be known before a period a simulated in SAGE, the slope and intercept have to be computed for year *t* using the production, cumulative production and economic resource base of year *t-1*.

Changes to Curve Shape (Shape Multiplier)

The original Hubbert equation is symmetric around the peak production rate. However, it is possible to represent a production pattern that is skewed toward faster depletion rates, such as that shown in Figure 3-2. Note that the areas under the two curves is the same since only the rate of explotation (not the resource base) is being changed.

The methodology developed here for SAGE allows for the Hubbert curve shape to be changed to represent an accelerated production pattern that might be expected in a high oil price environment. This would be done through a multiplier for production in any given period. This will allow SAGE to represent an increase in drilling activity and production that is greater than amount that would be obtained if oil price were only allowed to affect the size of the economic resource base. In other words, the price elasticity of production in any given year is usually made greater by the "shape multiplier" but is still subject to the binding limit of economic resource base. The suggested algorithm for the shape multiplier is presented in Section 7.

Figure 3-2 Hubbert Curve Shape Change for Accelerated Production Pattern



3.3 Methodology for WAU Model

EEA developed the World Assessment Unit (WAU) model to estimate the cost of oil and gas from over 500 "assessment units" (i.e., geologic plays) around the world for analyses of near- and long-term oil and natural gas production. The WAU allows use of country-specific tax and royalty concession terms and risk-adjusted rate of return requirements in cost calculations. The ninety-three countries represented in the WAU are shown in Table 3-1.

Table 3-1 Countries in WAU Model

Countries in WAU Model

	Country		Country		Country
1	Afghanistan	36	Gabon	71	Saudi Arabia
2	Algeria	37	Gambia	72	Senegal
3	Angola	38	Germany	73	Serbia
4	Argentina	39	Ghana	74	Slovakia
5	Australia	40	Greenland	75	South Africa
6	Austria	41	Grenada	76	Spain
7	Azerbaijan	42	Guinea	77	Sudan
8	Bahrain	43	Guyana	78	Suriname
9	Bangladesh	44	Hungary	79	Syria
10	Barbados	45	India	80	Thailand
11	Benin	46	Indonesia	81	Togo
12	Bolivia	47	Iran	82	Trinidad and Tobago
13	Brazil	48	Iraq	83	Tunisia
14	Brunei	49	Italy	84	Turkmenistan
15	Bulgaria	50	Kazakhstan	85	Ukraine
16	Cambodia	51	Kuwait	86	United Arab Emirates
17	Cameroon	52	Libya	87	United Kingdom
18	Canada	53	Malaysia	88	Uruguay
19	Chile	54	Malta	89	Uzbekistan
20	China	55	Mauritania	90	Venezuela
21	Colombia	56	Mexico	91	Vietnam
22	Congo (Brazzaville)	57	Morocco	92	Western Sahara
23	Congo (Kinshasa)	58	Myanmar	93	Yemen
24	Côte d'Ivoire	59	Namibia		
25	Croatia	60	Netherlands		
26	Cuba	61	Nigeria		
27	Czech Republic	62	Norway		
28	Denmark	63	Oman		
29	Ecuador	64	Pakistan		
30	Egypt	65	Paraguay		
31	Equatorial Guinea	66	Peru		
32	Eritrea	67	Poland		
33	Falkland Islands	68	Qatar		
34	France	69	Romania		
35	French Guyana	70	Russia		

USGS Assessment

In 2000, the U.S. Geological Survey published an assessment of remaining world oil and gas potential.[1] The assessment includes a characterization of undiscovered oil and gas resources by field size class. However, it does not include resource economics. EEA has processed the resource information to develop country level wellhead oil supply curves in the WAU.

The USGS assessment provides estimates of the quantities of conventional oil, gas, and NGL that have the "potential to be developed through 2025." The assessment does not include the United States, which had been assessed in 1995, and includes only a partial assessment of Canada. Only conventional oil and gas resources were quantitatively assessed although numerous non-conventional (tight, coalbed, and shale) plays were identified but not assessed. Ninety-six countries are evaluated. There are 246 assessment units (plays) in 128 geological provinces.

In addition to evaluating undiscovered fields, the USGS assessment is the first known published study to quantify reserve appreciation potential (growth in recovery of existing fields) at the world level. The approach used by USGS was to analyze a field level database of 33,000 fields and make the assessment by applying a "growth curve" to fields with a known discovery year. Both oil and gas reserve appreciation were assessed. EEA worked with the information available to develop our own assessment of appreciation that uses as much of the USGS work as possible. In developing the assessment, we also applied a cutoff "window" assuring that the estimate of reserve appreciation was within a boundary ranging from a lower bound of 30 percent of proved reserves to an upper bound of 50 percent of ultimate recovery.

WAU Processing

The WAU model takes inputs of 1) USGS resource base, 2) factor cost for drilling, well operation etc. and 3) financial assumptions and produces the costs of incremental resources. For crude oil this is $/bbl for each additional million barrels of proven reserves. The WAU is an Excel spreadsheet model created by EEA that that has the following logical steps:

1 - Resource base analysis. The model takes the USGS 2000 World Resource Assessment resource base descriptions for each Assessment Unit (AU or play) and adjusts the field size distributions using the "linear ratio model" that EEA employed for U.S., Canadian and Mexican resource bases during the 2003 NPC natural gas study. This process extrapolates the field size distributions to the smaller fields and corrects for inconsistent field size distributions among assessment methodologies and definitions. The use of the linear ratio model was intended by the NPC to create a standardized methodology for all regions of the U.S., Canada and Mexico and was expanded to the rest of the world in the WAU model. This linear ratio model assumes that the ratio of the ultimate number of fields in size class X to class X+1 declines as you go to smaller fields. This assumption tended to add resources to the assessment values, particularly to those of the MMS for offshore US regions. However, the linear ratio model adds less small field resources than does the assumption of a log-geometric small field distribution in which the ratio of between successive field size is assumed to be constant.

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[1] U.S. Geological Survey World Petroleum Assessment 2000 – Description and Results; USGS Digital Data Series DDS-60, 2000.

After the field size distributions are adjusted, the total resource base for each assessment unit is split up between onshore and offshore regions (where the AU includes both land and sea territory) and among countries (where the AU boundaries go across country boarders).

2 - Discovery process modeling. The WAU describes the way in which the undiscovered fields will be found during future increments of exploratory drilling. New discoveries are characterized by field size class. The fields are characterized further as having a hydrocarbon make-up containing a certain percent each of crude oil, dry natural gas, and natural gas liquids. Following the methodology used in EEA's Hydrocarbon Supply Model, the WAU uses a modified "Arps Roberts" equation to estimate the rate at which new fields are discovered. The fundamental theory behind the find-rate methodology is that the probability of finding a field is proportional to the field's size as measured by its areal extent, which is highly correlated to the field's level of reserves. For this reason, larger fields tend to be found earlier in the discovery process than smaller fields. The equation used by EEA accurately tracks discovery rates for mid- to small-size fields.

The find-rate equations are used in the model to predict the number of fields of a certain size that will be discovered after a given number of exploratory wells have been drilled. There are separate equations for each field-size class in an AU as allocated to each country and offshore/onshore region in that country. It is important to keep in mind that the result of the find-rate equations is a distribution of fields discovered for an increment of drilling somewhere along the discovery process. Because the large fields are more likely to be found relatively early, the distribution in the first stages of the exploration process contains a relatively high number of large fields along with the medium and small size fields. However, in the later stages of the process, the distribution contains only medium and small size fields. The results of the find-rate equations represent the expected value of field discoveries per size class. This is conceptually similar to averaging the results of a large number of Monte Carlo simulations in which the probability of discovering a field is related to its areal extent.

3 - Discounted cash flow analysis. The WAU model calculates a simple DCF for each increment of drilling and the resource cost of oil ($/bbl) for that increment using an assumed tax and royalty regime for each country. This is based on drilling, equipment and operating cost factors and equations that represent typical costs based on environment (onshore drilling depth, offshore water depths). These typical cost factors are derived from cost that were developed during the 2003 NPC gas study for each drilling environment and can be further adjusted in the WAU with AU-specific cost adjustment factors.

Each field size is evaluated separately in terms of development costs and what threshold price is needed to make its development and production worthwhile. The total cost for each exploration increment is the exploration cost plus the development cost for each field size that is economic. The resource cost of an increment is defined as the cost of oil needed to pay all exploration, development, production costs, taxes and costs of capital.

4 - Long run supply curve generation. The final step in the WAU is to generate a curve representing the cost of finding, developing and producing each additional increment of crude oil. The quantity of oil developed in each increment and the average resource cost of each increment are the elements that make up the crude oil supply curves. Curves can be created for each country/AU, for each country or for the multi-country regions defined by the USGS.

Financial Assumption for Oil Supply Curves

The most important financial assumptions include:

- 60% equity financing at a nominal rate of return of 18%
- 40% debt financing at a nominal annual interest rate of 7%
- Inflation at 2.5% per year

Since the curves are meant to represent long-run economic potential, the fiscal regime in each country was modeled using a standard set of assumptions rather than current petroleum taxation policies. This standard regime assumed:

- 20% royalty payment
- 50% income tax payment
- straight-line depreciation of capital costs
- royalties and operating cost are deductible for income tax purposes

One commonly used measure of the severity of petroleum fiscal regimes is the "undiscounted government take" which is computed as the sum of royalties and taxes as a percent of the "rent". The rent, in turn, is the revenue minus all investment and operating costs, wherein no allowance is made for the time value of money. The standard assumptions used for the supply curves yield an undiscounted government take of 65% which is about the average of actual values reported in a study sponsored by the World Bank.[2]

The curves represent the real price needed for the gas to pay all operating costs, debt payments, royalties, income taxes and to yield the required return on equity over a project period assumed to be 20 years.

Representation of Technology Improvement in WAU

The basic cost factors in WAU represent circa year 2000 drilling, equipping and operating costs. The effect of technology progress can be represented by specifying a per annum improvement in technology factors that reduce the effective costs of exploration, development and production. For the results shown in this documentation that factor was set at 1.5 percent per annum for 25 years. In other words, the curves represent the resource costs with year 2025 technology.

For operation within SAGE, this process can be used and the curve data can be input to represent technology as of a future year. Alternatively, WAU could be run with a zero technology improvement factor and something could be done within the preprocessor to adjust for each periods technology level.

[2] "A Comparative Study of World Fiscal Systems for Oil and Government to Government Competition," by Pedro van Meurs (Gordon Barrows, New York, 1997.

4 WOLM LAYOUT, OPERATION & RESULTS

The Excel spreadsheet file "World Oil Logistic Model.xls" contains all of the data, formulas, and VBA code that comprise the model. The model is organized such that input data, lookup tables, calculated values, and model output are located on tabbed "worksheets" within the master Excel "workbook". Most of the worksheets contain a standard country name in the far left column (usually column A) of the data range. A lookup function is used to fill in the WOLM standard country name using the reported name and a lookup table (worksheet LOOKUP).

The contents and data sources of the individual worksheets are summarized below. The DRIVERS and CALC worksheets are discussed in greater detail in the Model Operation section of this document.

Sheet:	**README**
Contents:	Documents model layout, data sources, and formulas

Sheet:	**LOOKUP**
Contents:	This table relates the as-reported country name to the WOLM standard country name and three different region groupings.
Columns:	as-reported country, standard country, orig order, SAGE order, SAGE region, SAGE code, OPEC flag, IEO_tabE4 order, IEO_tabE4 region, source.

Sheet:	**DRIVERS**
Contents:	setup and user inputs
Source:	Developed by EEA.
Notes:	This sheet is discussed in detail in the Model Operation section.

Sheet:	**CALC**
Contents:	Master calculation sheet that generates the forecast
Source:	Developed by EEA.
Notes:	Units are billion barrels, except where otherwise labeled. This sheet is discussed in detail in the Model Operation section.

Sheet:	**OUTPUT**
Contents:	Individual country historical and forecast data 1980-2100, units: billion bbl.
Source:	Developed by EEA.
Notes:	Cleared and recreated each time the macro runs.

Sheet: **WorldPivot**
Contents: Pivot table totals data in sheet OUTPUT and compares to single-point world forecast
Source: Developed by EEA.

Sheet: **RegionPivot**
Contents: Pivot table sums data in sheet OUTPUT by region
Source: Developed by EEA.

Sheet: **OILPROD**
Contents: Annual crude oil and condensate production 1980-2003, units: kbbl/day
Source: EIA International Energy Annual 2003 Table 2.2, http://www.eia.doe.gov/pub/international/iealf/table22.xls
Notes: Column A contains lookup formula to standard country name. Formula in Germany row sums pre-1991 East and West Germany. FSU historical data are in rows 255-258. Annual production from 1980 through 1995 is summed in column AK.

Sheet: **ADJPROD**
Contents: Unconventional oil production 1980-2003, units: kbbl/day. CONTAINS ONLY THOSE VOLUMES THAT ARE REPORTED IN EIA TABLE22.xls!
Source: Canadian Association of Petroleum Producers (CAPP) http://www.capp.ca/raw.asp?x=1&dt=NTV&e=PDF&dn=80642
Notes: The purpose of this sheet is to break out unconventional volumes contained in EIA table22.xls. Currently only Canadian oil sands production is reported, but the sheet provides a framework to add other countries if needed.

Sheet: **CONVPROD**
Contents: Annual conventional crude oil and condensate production 1980-2003, units: kbbl/day
Source: Calculated from sheet OILPROD minus sheet ADJPROD.
Notes: Conditional formula used to filter #N/A values. FSU historical data in rows 255-258; Australia/Indonesia Zone of Cooperation and Joint Thailand/Malaysia rows 260-261 to conform to countries in USGS assessment.

Sheet: **USGSCUM**
Contents:
1. USGS cumulative crude oil and cumulative NGLs production through year-end 1995, units: MMbbl
2. Sum of annual production from 1980 through 1995.
3. Mean undiscovered crude oil and NGLs, units: MMbbl

Source: USGS 2000 Assessment.
Notes: Sum of annual production presented next to USGS cumulatives - sum of annual used in cases where USGS data missing or less than sum of annual. Contains formulas to allow the user to specific a condensate fraction of NGLs for inclusion in the crude and condensate total.

Sheet: **OILCUM**
Contents: Cumulative conventional crude oil and condensate production time series 1980-2003. Each value is through year end, units: MMbbl
Source: Calculated from year-end 1995 value by adding or subtracting annual production.
Notes: Annual production is adjusted to remove the oil sands production.

Sheet: **LIQCUM**
Contents: Cumulative conventional crude oil and condensate production 1980-2003, units: MMbbl
Source: sheet OILPROD.
Notes: Conditional formula used to filter #N/A values.

Sheet: **RESERVES**
Contents: Annual January 1 proved reserves, 1980-2006, units: billion bbl.
Source: Oil and Gas Journal data compiled by EIA http://www.eia.doe.gov/pub/international/iealf/crudeoilreserves.xls
Notes: Inserted column A which contains lookup formula to standard country name. Canada reserves (row 13) and World Total (row 132) adjusted to remove Oil Sands 2003-forward; FSU historical data calculated in row 134.

Sheet: **GROWTH**
Contents: Crude oil and NGLs reserve growth, units: MMbbl.
Source: EEA estimates based on USGS 2002 Assessment.
Notes: Contains formulas to allow the user to specific a condensate fraction of NGLs for inclusion in the crude and condensate total.

The following worksheets are not used in the WOLM forecasting process. These data are included for comparison with International Energy Outlook Table E4.

Sheet: **NGLPROD**
Contents: Annual plant liquids production 1980-2003, units: kbbl/day
Source: EIA International Energy Annual 2003 Table 2.3 http://www.eia.doe.gov/pub/international/iealf/table23.xls

Sheet: **OTHERPROD**
Contents: Annual production of "other" liquids 1980-2003, units: kbbl/day
Source: EIA International Energy Annual 2003 Table G4 http://www.eia.doe.gov/pub/international/iealf/tableg4.xls

Sheet: **REFGAIN**
Contents: Annual refinery gain 1980-2003, units: kbbl/day
Source: EIA International Energy Annual 2003 Table G5 http://www.eia.doe.gov/pub/international/iealf/tableg5.xls
Note: volumes can be negative.

Sheet: **TabE4**
Contents: Pivot table sum of production by IEO regions; comparison to IEO Table E4; sums of NGL, refinery gain, and other 2002 production for comparisons to IEO Table E4.
Source: various EIA tables.

4.1 Model Operation

4.2 Quick Start

- Check printout toggle in worksheet DRIVERS cell G9. Y=print each country, N=no printout.
- Run the macro WorldOil1: Excel Menu>Tools>Macro>Macros - highlight WorldOil1 - click RUN.
- View summaries of forecast results written to worksheets WorldPivot and RegionPivot. Individual country forecasts are written to worksheet OUTPUT.

4.3 Summary

The WOLM forecast is produced in worksheet CALC. Worksheet CALC operates on a single country by compiling input data and parameters from worksheets DRIVERS, CONVPROD, LIQCUM, RESERVES, OILWELLS, and OPERWELLS. The forecast for a particular country is selected by entering the country number in cell X1 (range conum). The macro WorldOil1 automates this forecast process by looping through all 117 countries and World Total, writing results to worksheet OUTPUT, and updating the two pivot tables in worksheets WorldPivot and RegionPivot.

4.4 *Model Input Parameters - Worksheet Drivers*

This sheet contains three data ranges where the model user can modify the input parameters used in worksheet CALC to produce the oil production forecast. The three data ranges are: Global Model Parameters, Oil Price Forecast, and Country-specific parameters in range PARMS.

4.4.1 Global Model Parameters

Global parameters used in this sheet and in sheet CALC cells G1:G9.

Cell	Label	Notes
G1	Num_countries	number of countries in list, used by macro (see column E)
G2	global_startyr	not currently used
G3	RB_price_lag	years for full impact of oil PRICE to be felt
G4	Yroffset	column offset for time series data
G5	number of years	number of years in forecast (sheet CALC)
G6	default P/CUM starting value	used to calculate a default slope for non-producing countries
G7	default EUR/well (mmbbl)	
G8	default productivity (bblday)	
G9	print each results of each country (Y/N)	

4.4.2 Oil Price Forecast

Enter an oil price forecast out to year 2100 in cells B13:B110. The current forecast is taken from the from AEO 2006 Table 12 Imported Crude Oil price ($2004), with years 2030-2100 projected at 0.8%/yr real increase as per out years of AEO forecast.

4.4.3 Range PARMS

Country-specific parameters for the forecast in sheet CALC cells E13:AG130.

Column	Name	Notes
E	Country number	A sequence number used by macro to loop through this list.
F	Standard Country	WOLM standard country name
G	Process	Y=process, N=skip
H	Startyr	(not used)
I	Country startyr	(not used)
J	P1	first price, quantity pair from 3 point curve
K	RB1	first price, quantity pair from 3 point curve
L	P2	Second price, quantity pair from 3 point curve
M	RB2	Second price, quantity pair from 3 point curve
N	P3	third price, quantity pair from 3 point curve
O	RB3	third price, quantity pair from 3 point curve
P	Parm1	Oil price threshold above which the production curve shape is adjusted
Q	Parm2	Price above threshold is multiplied by this factor. Value of 0.002 means 10% change for a fifty dollar per barrel swing in oil price.
R	Locbasis	Place-holder for country-specific price adjustment (not used).

Column	Name	Notes
S	Default Intercept	Default intercept in simple "Hubbert" equation of p/cum = int + slope*cum. Used for countries without historical data. Calculated as -1*RB*slope
T	Default Slope:	Used for countries without historical data. Calculated as p/cum starting value divided by RB. The p/cum starting value is currently implemented as a global parameter (cell G6).
U	Operating Oil Wells:	Used to calculate average productivity (column AD)
V	Conv prod Kbbldy:	Used to calculate average productivity (column AD)
W	Liquids Cumprod Bbbl:	Cumulative production lookup from sheet LIQCUM, used in RB calculation.
X	Reserves Bbbl:	Proved reserves lookup from sheet RESERVES, used in RB calculation.
Y	Growth liquids Bbbl:	Reserve growth lookup from sheet GROWTH, used in RB calculation.
Z	New Fields Liquids Bbbl:	New fields undiscovered resource lookup from sheet USGSCUM, used in RB calculation.
AA	RB Bbbl:	Resource Base = cumprod + reserves + growth + new_fields
AB	RB year:	Base year. Note that non-producing countries have future base years.
AC	EUR/well:	Very rough estimate historical EUR/well (MMbbl). Should be calculated as all-time EUR divided by historical oil wells. Unfortunately, historical oil well count is unknown, so historical oil wells are approximated by 2 times operating oil wells in the calculation. Used only if an EUR cannot be calculated from recent years' reserve additions and annual well completions in sheet CALC.
AD	oil BBL/day/well:	Average well productivity = production divided by operating wells. Used if average of recent years not available in sheet CALC.
AE	Use Default Parms:	Flag to use default intercept and slope in Hubbert equation.
AF	EUR/well annual decline:	Annual decline in average EUR per new well.
AG	Productivity annual decline:	Annual decline in average well productivity.

4.5 Forecast Engine- Worksheet CALC

Worksheet CALC has three main areas of interest: input parameters read from sheet DRIVERS and calculated in the top left area (cells B1:U17), historical and calculated time series data in area A20:U140, and a report in area V1:AK83.

- Input Data and Parameters (range B1:U17). The cells in this range contain data populated using lookups from the PARMS range of worksheet DRIVERS (e.g., RB year), calculated here from the DRIVERS parameters (e.g., RB Price Sensitivity coefficients in cells F7 and F8), and

- Historical and Calculated Time Series Data (range A20:U140)
- Report (range V1:AK83)

Column	Variable	Excel formula	Explanation
A	Year		
B	Price	=VLOOKUP(A44,prices,2,FALSE)	prices range in DRIVERS sheet
C	Full RB	=IF(A44=RB_year,1,$G$3+$F$7*((B44-$F$3)/($F$5-$F$3))^$F$8)	RB supply curve function
D	RB	=IF(A44=RB_year,RB, IF(A44>RB_year,D43+((C44*RB)-D43)/RB_price_lag,""))	Scaled RB, note parameterization to phase in price response over RB_price_lag years
E	Cum	=IF(A44>RB_year,E43+F43,VLOOKUP($C$2,liqcum!$A$13:$AM$261,$A44-yroffset-1,FALSE)/1000)	Beginning of year cumulative production
F	Prod	=IF(A44>RB_year,E44*G44,IF(AND(A44=RB_year,C$14=0),C$16,VLOOKUP($C$2,convprod!$A$13:$AM$261,$A44-yroffset,FALSE)*0.000365))	= (prod/cumprod) * (beginning of year cumprod). If no production history, use C$16 as starting value.
G	P/Cum	=IF(A44>RB_year,H44+E44*I44,IF(E44>0.000000000000001,F44/E44,NA()))	Hubbert equation: prod/cumprod = int + slope*cumprod; check for tiny value in historical years (caused by rounding error)
H	INT	=L44+((J44-J43)*L44)	Final intercept for P/Cum equation after shape adjustment has been made. Note that because shape effect accumulates in to intercept value DIFFEREENCE from last year's shape multiplier is used here.
I	SLOPE	=-H44/D43	Final slope calculated as = -INT/RB. This resets slope after initial intercept had shape adjustment.
J	Shape multiplier	=MAX(MIN(MAX(0,B45-Parm1)*Parm2,J44+0.005),J44-0.005)	Changes curve shape by adjusting intercept by this fraction of unadjusted value. However, it can't changed by more than 0.005 from prior year value. Shape adjustment skews the Hubbert equation to the left (i.e., accelerates production) at higher oil prices.
K	Initial SLOPE	=IF(AND(C$15="Y",A44<RB_year+2),C$13,(F43/E43)/(E43-D43))	Slope calculated from prior year data, non-producing countries use default slope as starting value (C$15="Y" means use default). This is slope

Column	Variable	Excel formula	Explanation
			value before shape adjustment is made.
L	Initial Intercept	=D43*-K44	Intercept for P/Cum equation = RB * -slope. This is value before shape adjustment is made.
M	CumProd /RB	=IF(A44<RB_year,E44/RB,E44/D44)	Cumprod as fraction of RB
N	R/P	=IF(A44>RB_year,$M$17+$M$16*M44,P44/F44)	Forecast period R/P ratios calc as linear function of cumprod/RB
O	Cum Reserves	=P44+E44	Ultimate recovery = cumprod + reserves
P	Reserves	=IF(A44>RB_year,F44*N44,VLOOKUP($C$2,reserves!$A$13:$AI$135,$A44-yroffset+1,FALSE))	Forecast period reserves calculated from R/P * prod
Q	Res Adds	=O44-O43	Change in EUR. This value may become negative when initial reserves are a very high multiple of production.
R	annual oil wells	=ROUND(IF(A44>RB_year,MAX(1000*Q44/U44,S43*0.01),VLOOKUP($C$2,oilwells!$A$13:$AM$243,$A44-yroffset,FALSE)),0)	Annual wells = annual rur adds / eur_well. However, new wells must be at least 1% of existing operating wells. Minimum will apply when reserves adds are very low or negative.
S	operating oil wells	IF(A44>RB_year,1000000000*F44/T44/365,VLOOKUP($C$2,operwells!$A$13:$AM$128,$A44-yroffset,FALSE))+IF(ISNA(R44),0,R44)	Operating wells = production / average_prod_per_well
T	avg BBL / day /well	T$15*(1-T$17)^(ROW()-row1-1)	Average last 3 years * annual decay function
U	approx. EUR per well	U$15*(1-U$17)^(ROW()-row1-1)	Average last 3 years * annual decay function. If historical EUR and wells are not available, then a rough estimate of EUR/well is used. This rough estimate is calculated in the DRIVERS sheet as country_EUR / country_historical_wells, where country historical wells are approximated as 2 or 3 times the operating wells.

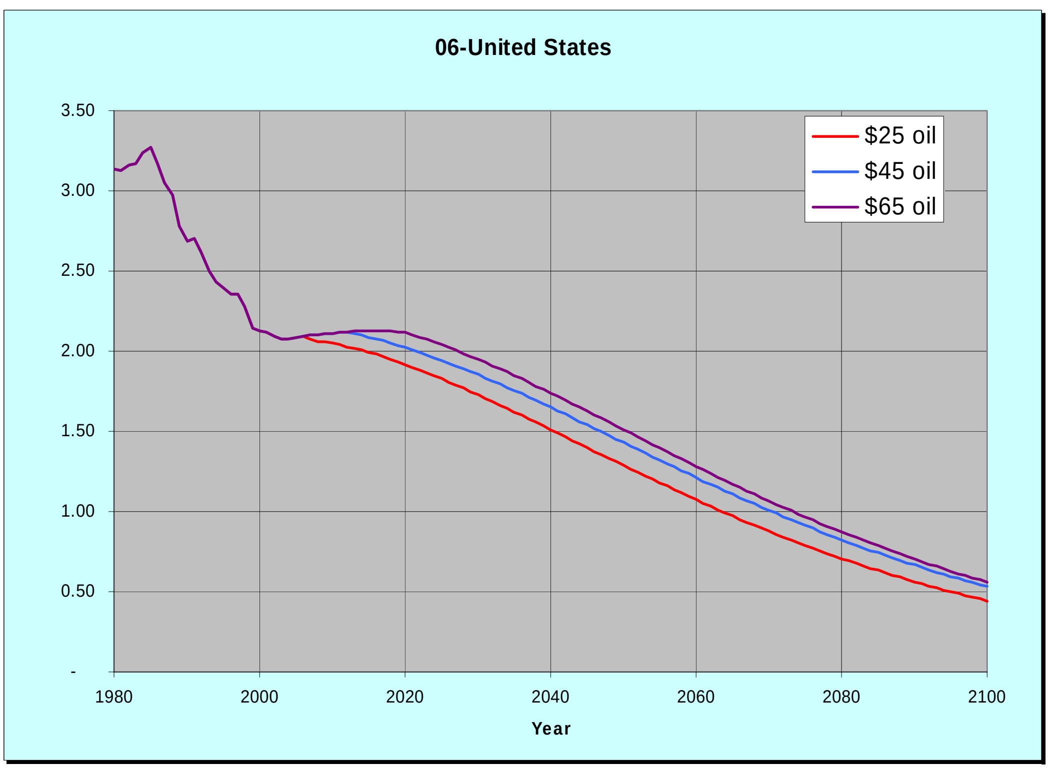
4.6 VBA Macro WorldOil1

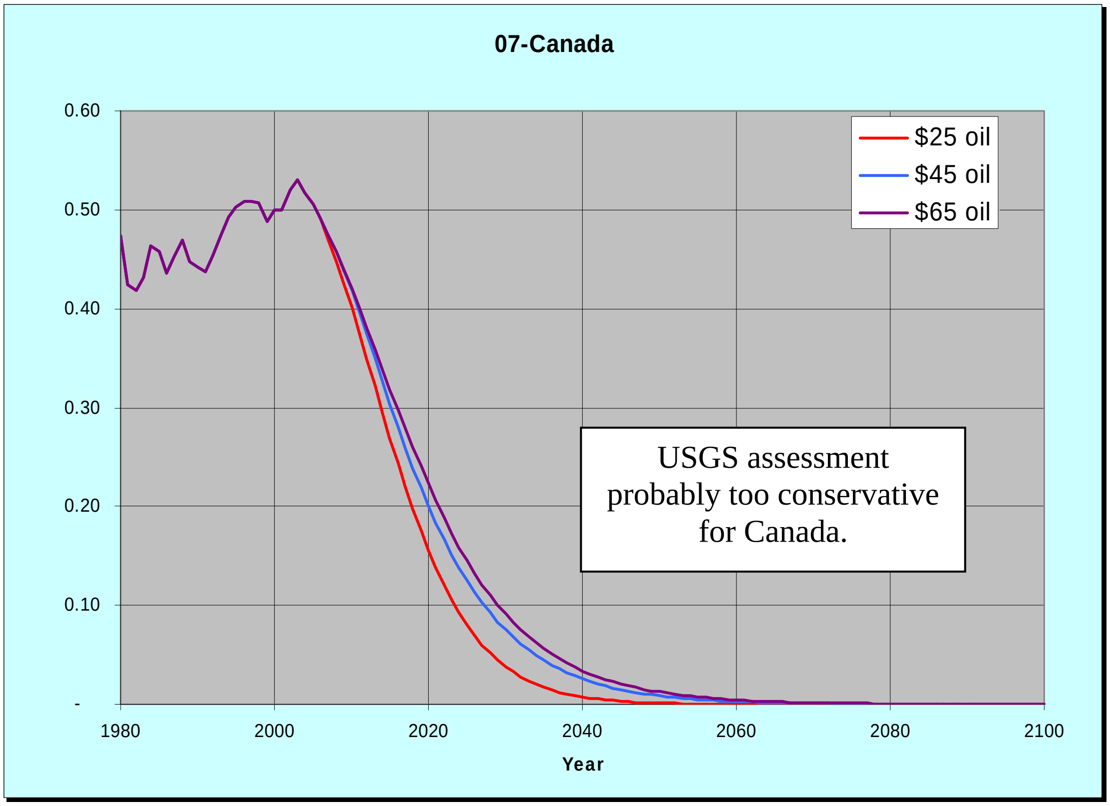
The VBA macro WorldOil1 automates the following actions:

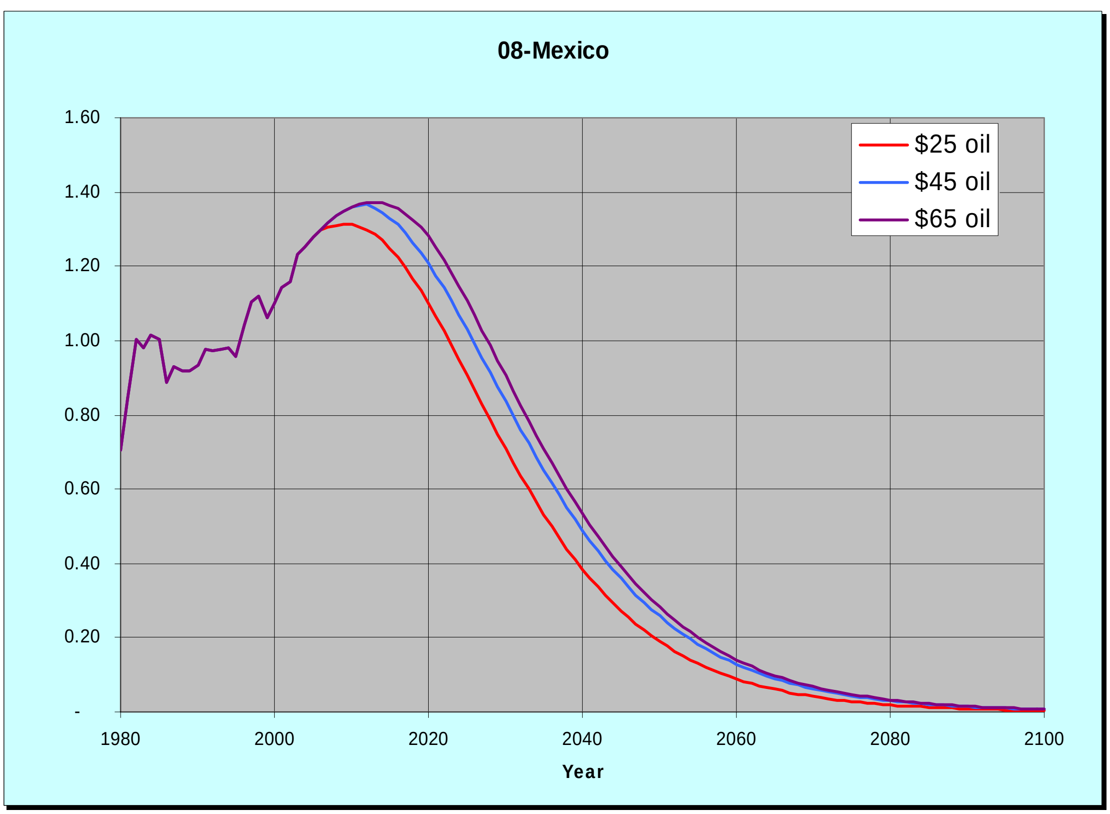
- Changes the country number in worksheet CALC range conum.
- Prints the forecast for each country if the printout switch is toggled to Y.
- Copies the geographic identification and forecast results from sheet CALC and pastes into sheet OUTPUT, appending each new country below the prior country. Non-numeric values (e.g., #N/A) are filtered prior to pasting into this worksheet.
- Updates pivot table data that are sourced from worksheet OUTPUT.

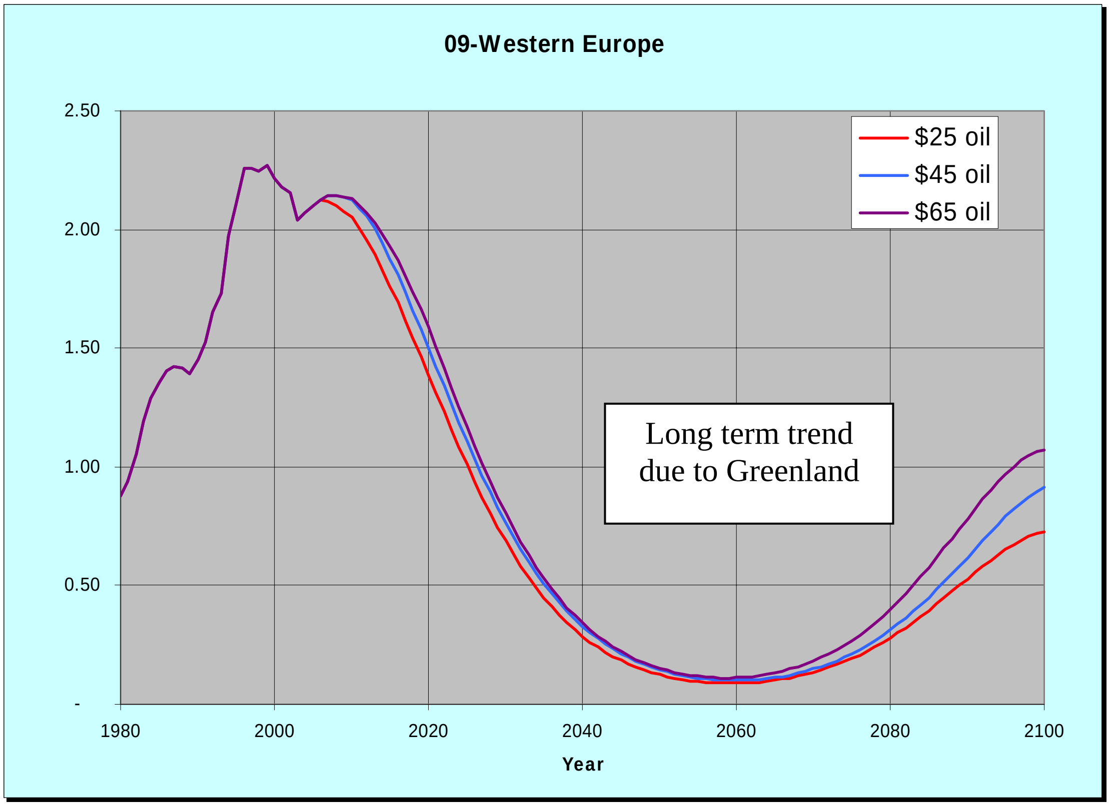
4.7 WOLM Outputs

The WOLM model was tested with alternative assumptions for oil prices of $25, $45 and $65 per barrel. The results for various non-OPEC regions are shown in the figures below. Production is for annual conventional crude oil and lease condensate in billion barrels per year. Note that OPEC countries are excluded from graphs except for last chart showing the world total.

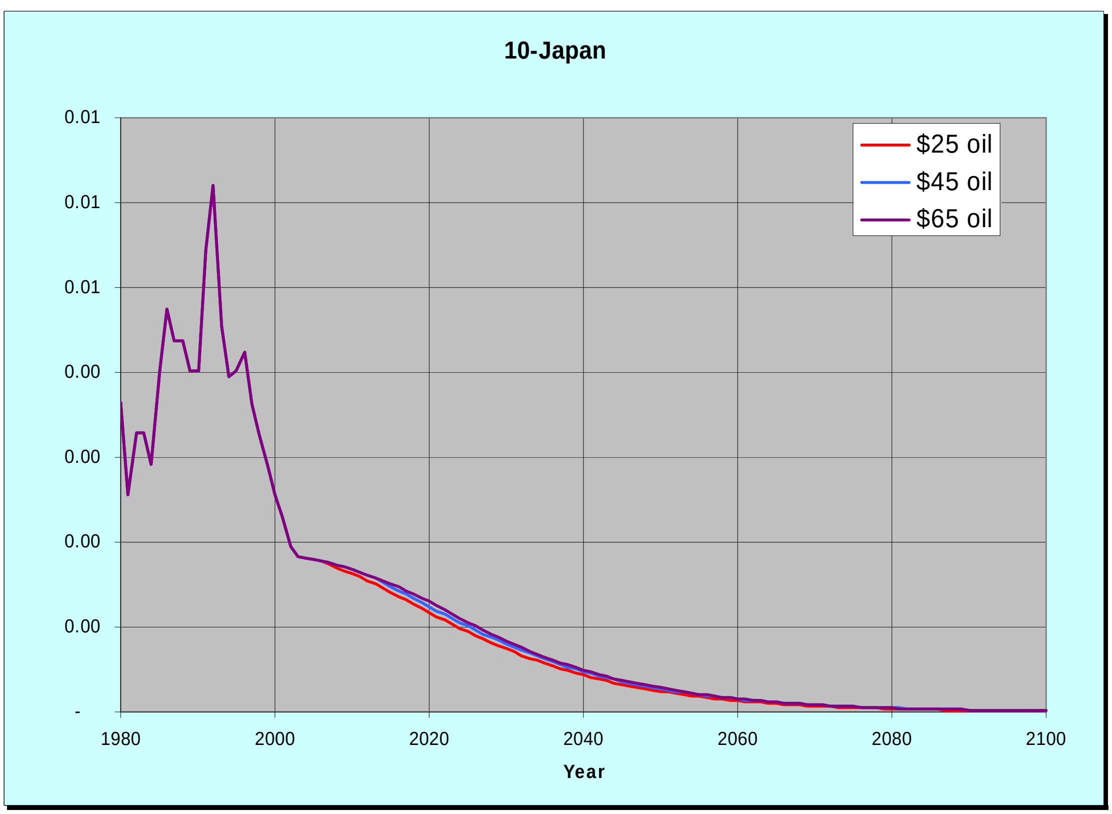



07-Canada
0.60
0.50
0.40
0.30
0.20
0.10
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil
USGS assessment probably too conservative for Canada.

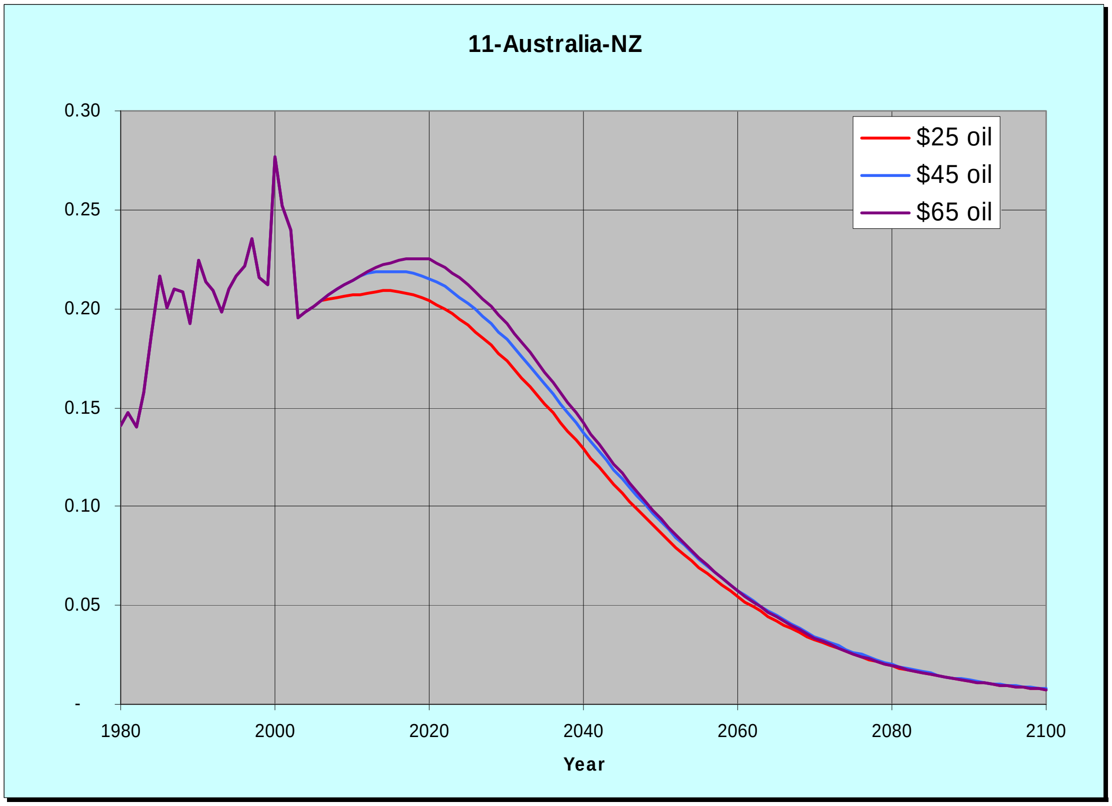

08-Mexico
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil

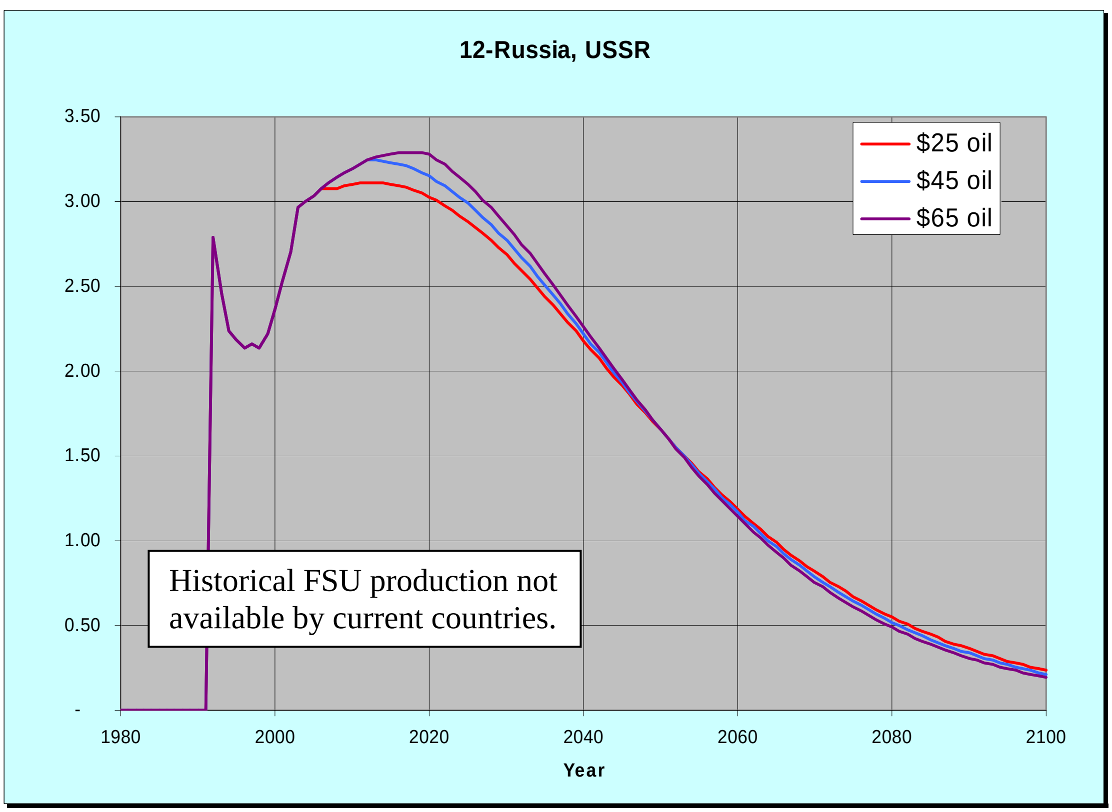


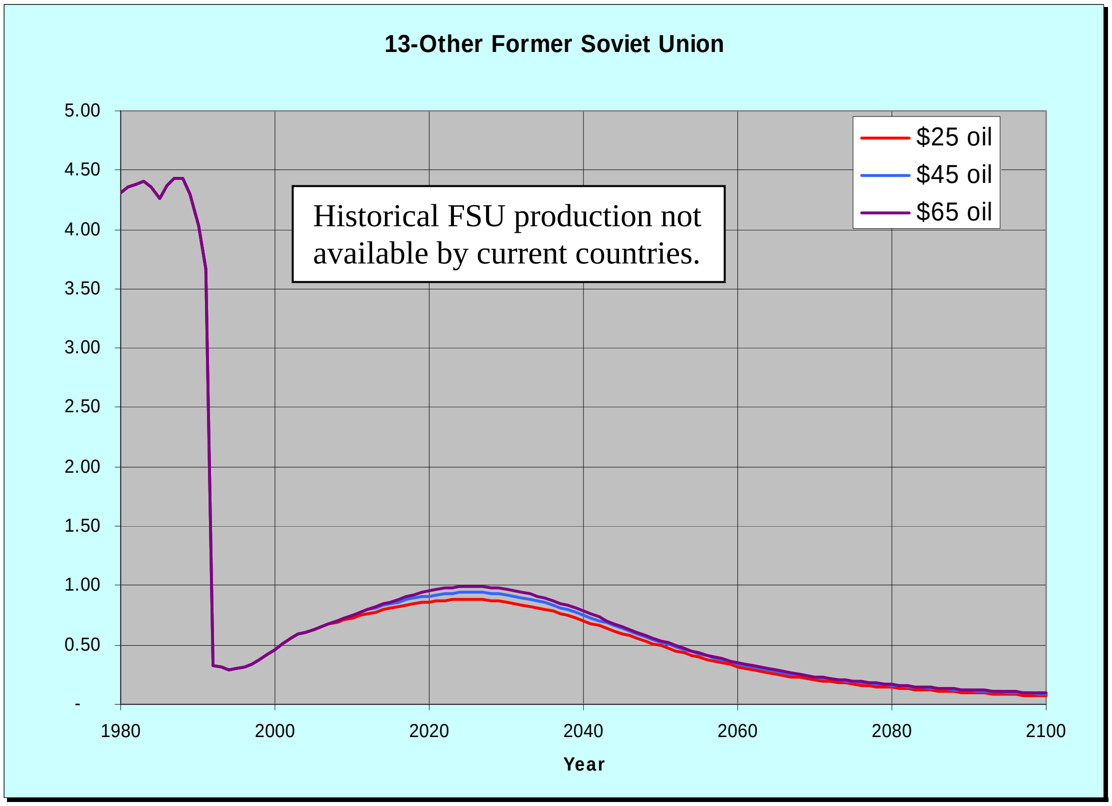
09-Western Europe
2.50
2.00
1.50
1.00
0.50
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil
Long term trend due to Greenland

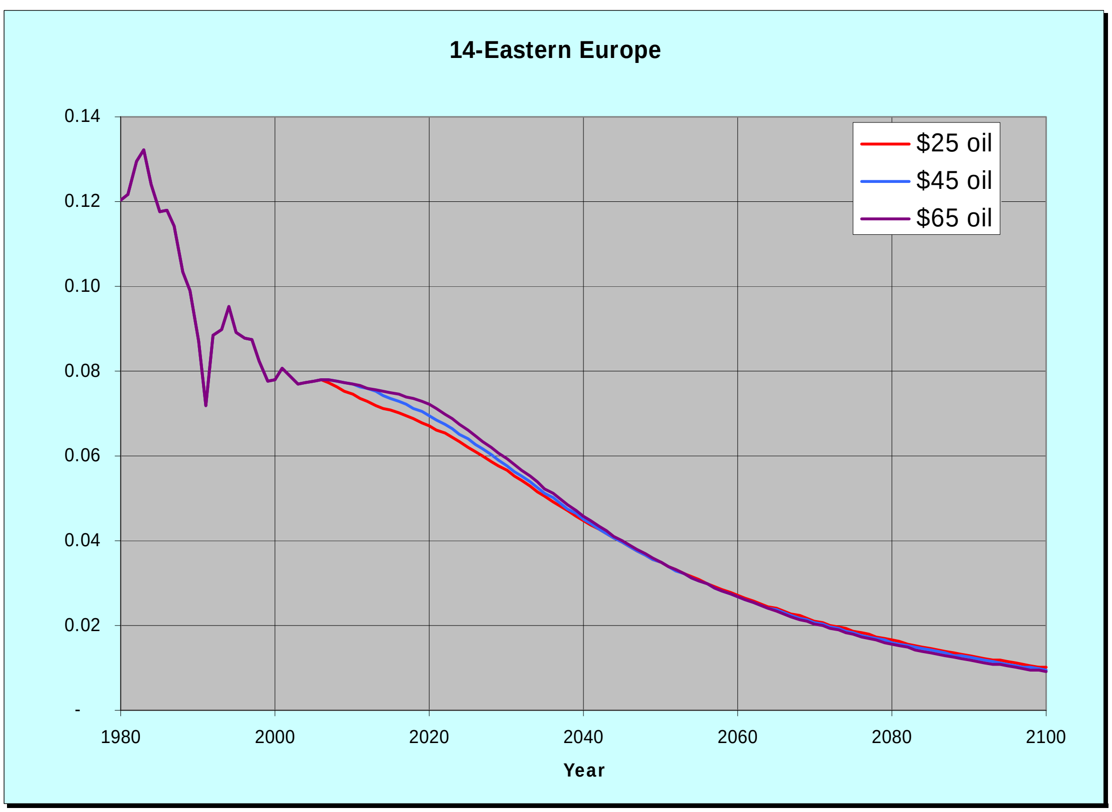


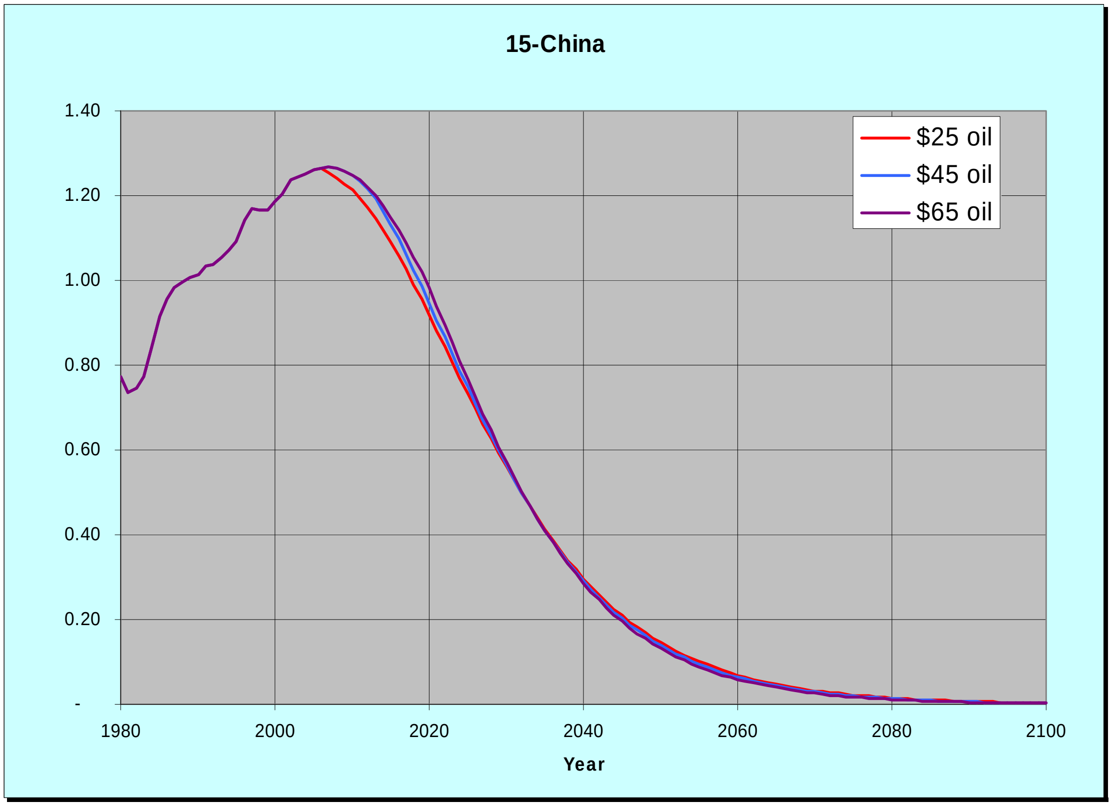
10-Japan
0.01
0.01
0.01
0.00
0.00
0.00
0.00
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil

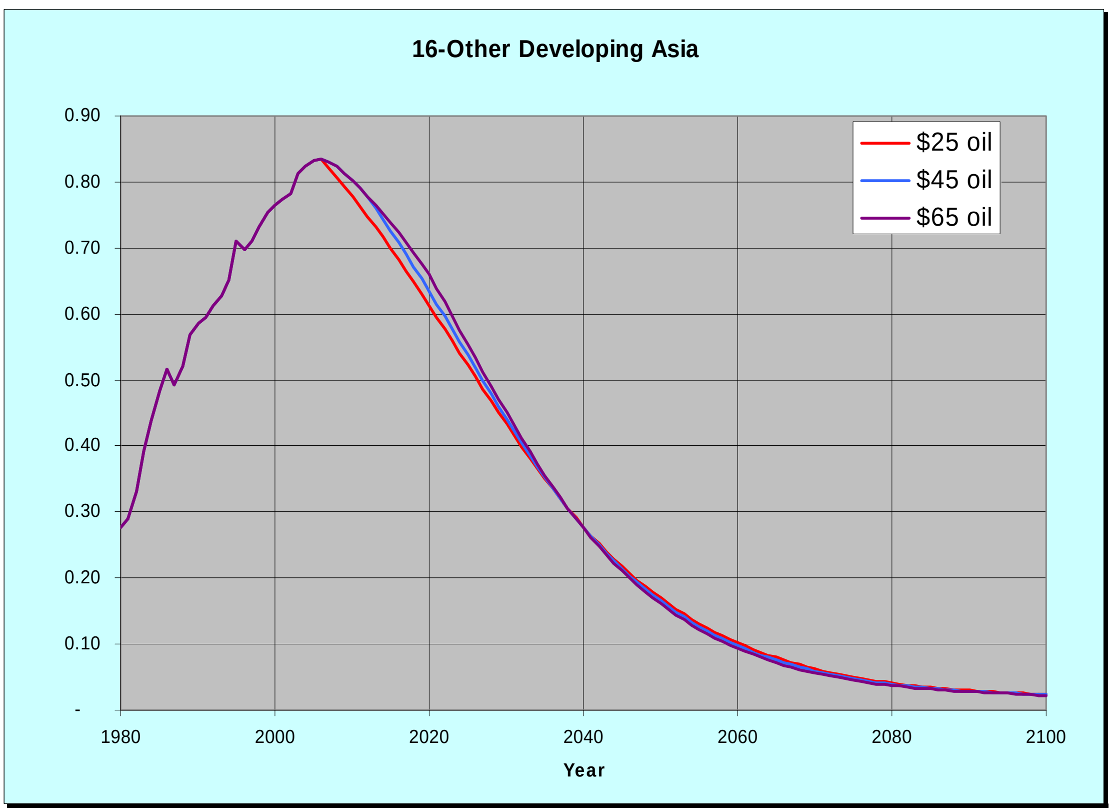

11-Australia-NZ
0.30
0.25
0.20
0.15
0.10
0.05
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil

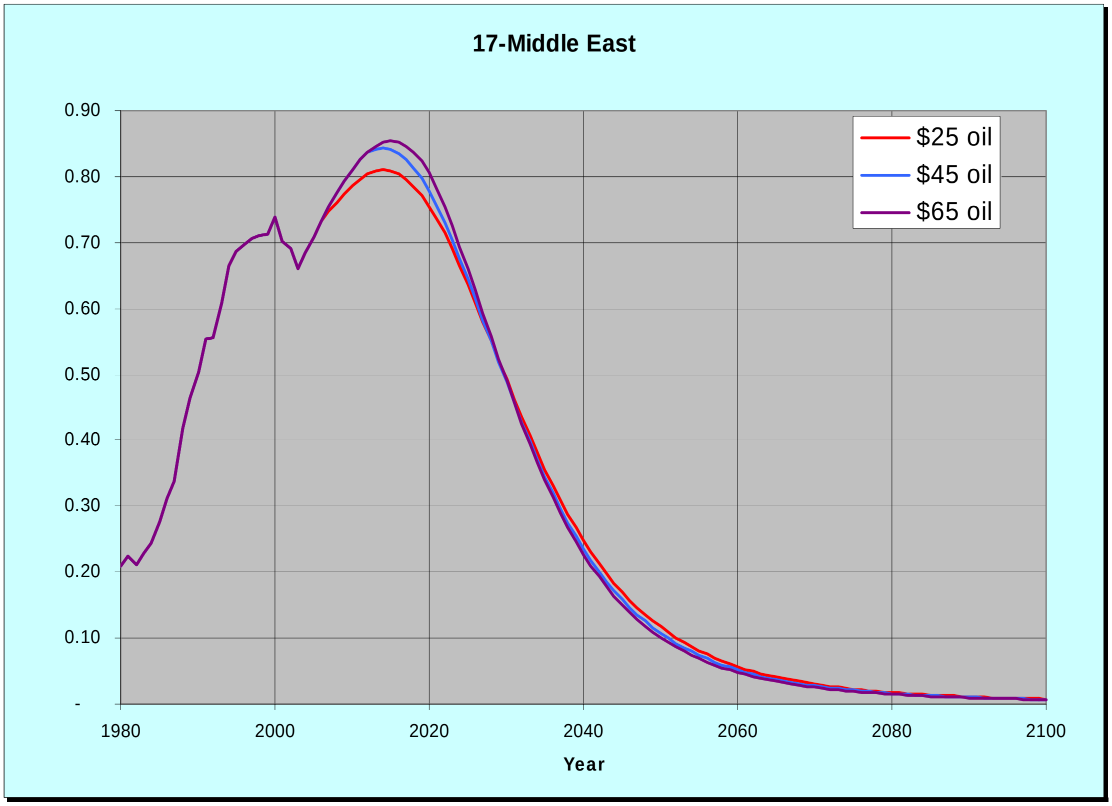

12-Russia, USSR
3.50
3.00
2.50
2.00
1.50
1.00
0.50
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil
Historical FSU production not available by current countries.

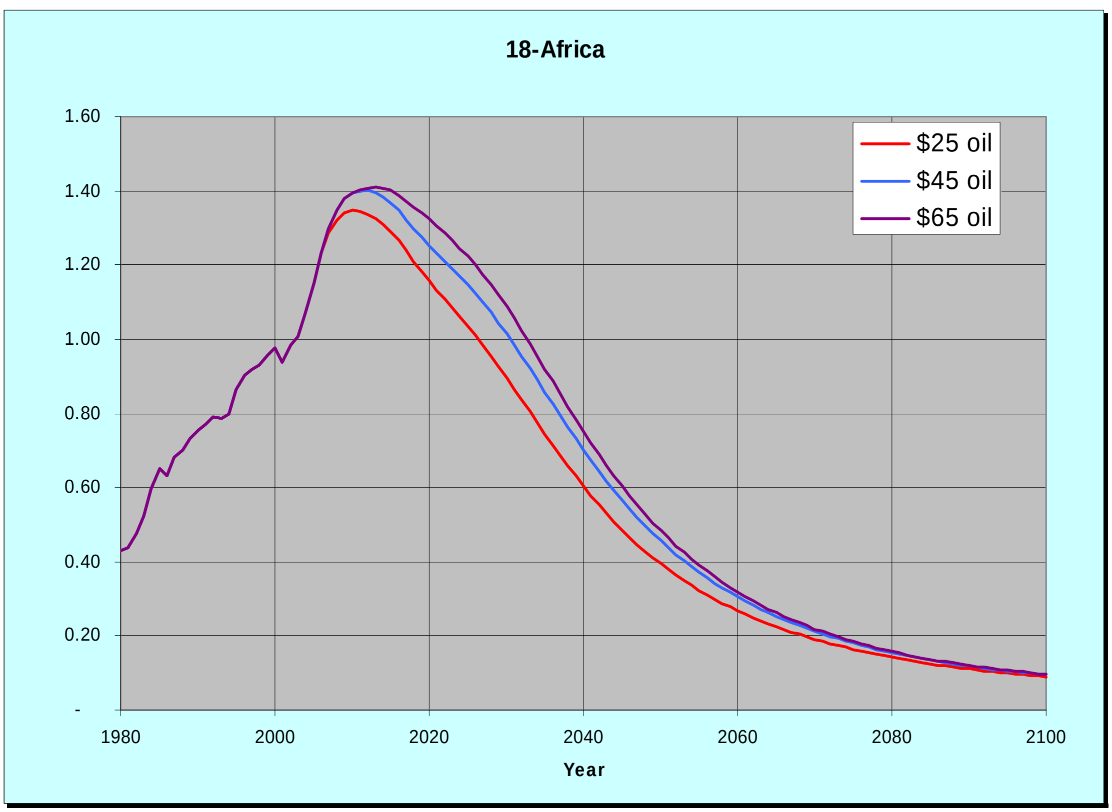

13-Other Former Soviet Union
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil
Historical FSU production not available by current countries.

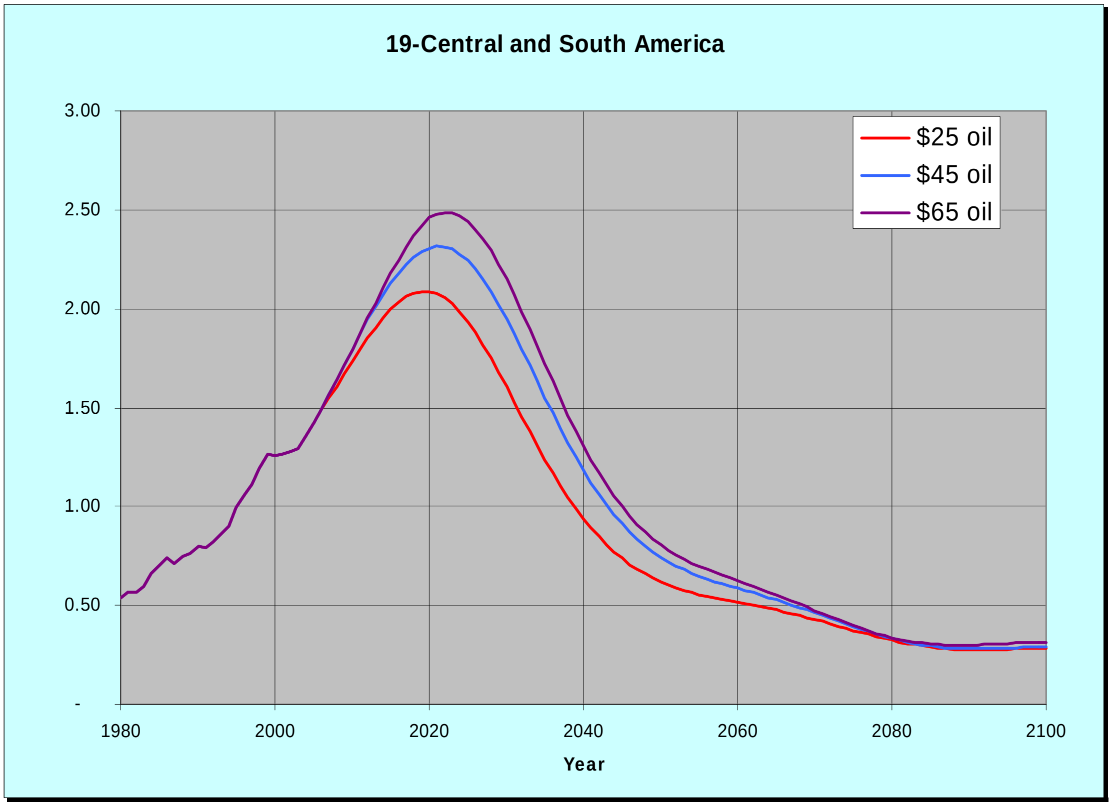

14-Eastern Europe
0.14
0.12
0.10
0.08
0.06
0.04
0.02
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil

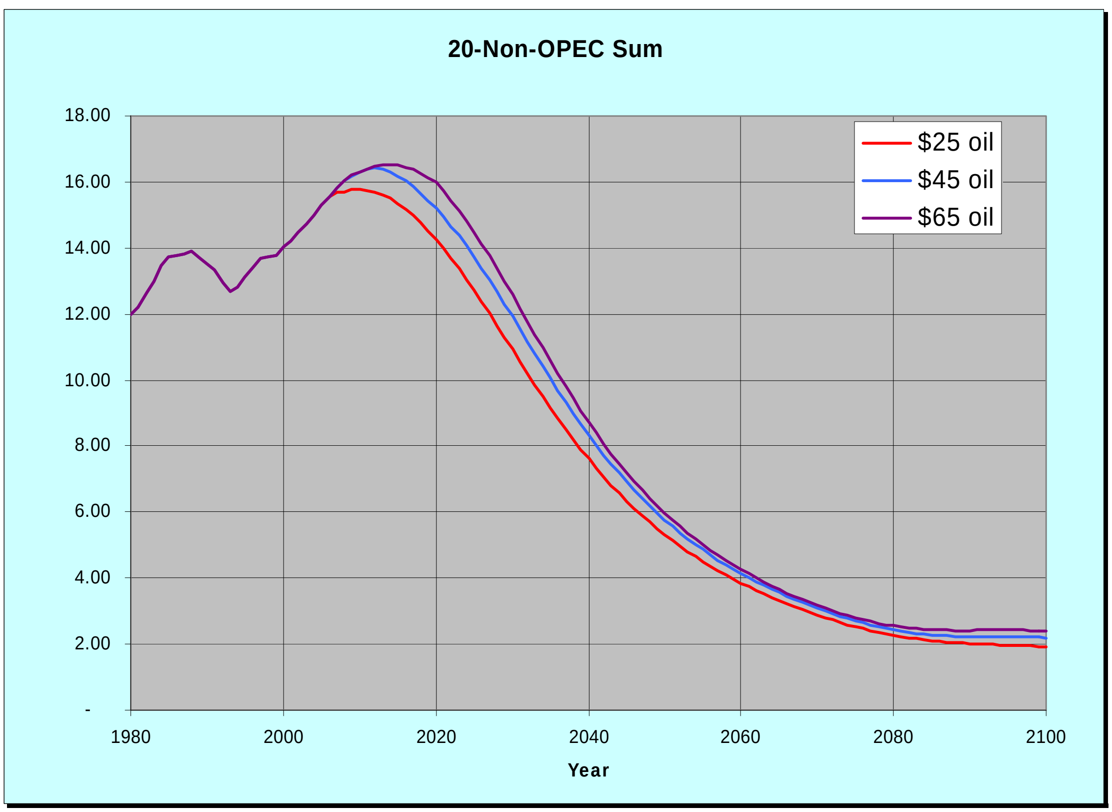

15-China
1.40
1.20
1.00
0.80
0.60
0.40
0.20
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil

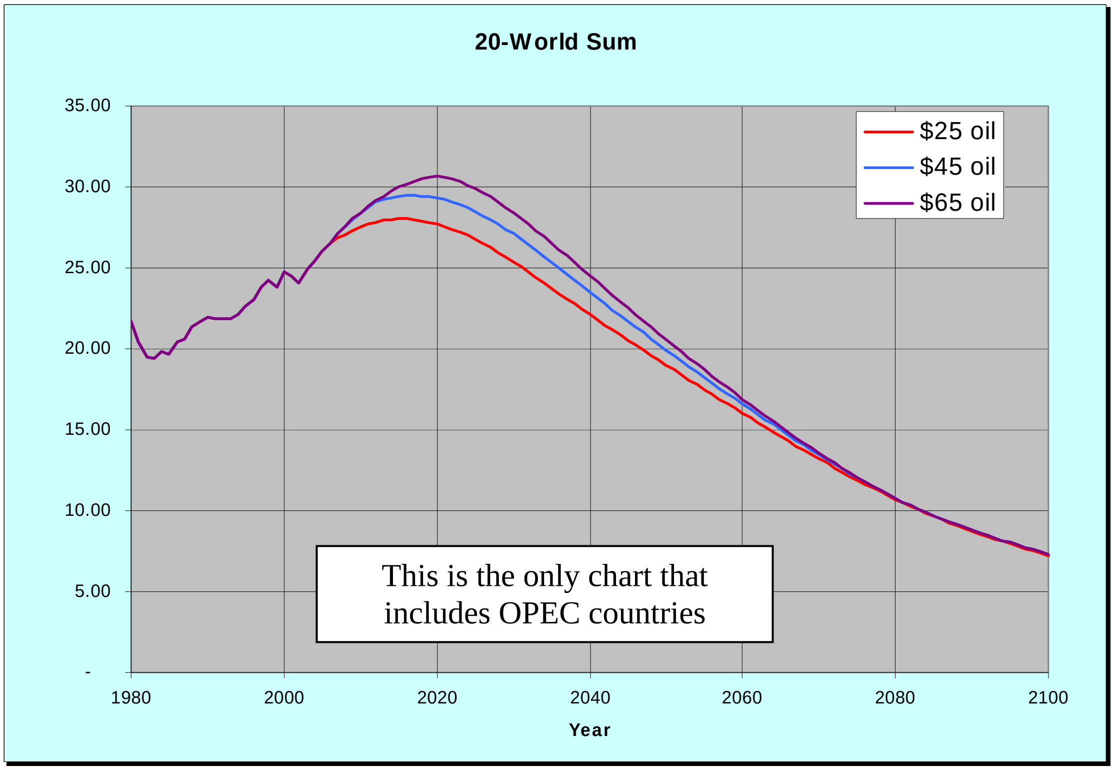

16-Other Developing Asia
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil


17-Middle East
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil


18-Africa
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil


19-Central and South America
3.00
2.50
2.00
1.50
1.00
0.50
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil


20-Non-OPEC Sum
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil


20-World Sum
35.00
30.00
25.00
20.00
15.00
10.00
5.00
-
1980
2000
2020
2040
2060
2080
2100
Year
$25 oil
$45 oil
$65 oil
This is the only chart that includes OPEC countries

5 UPDATING

5.1 Annual Production

1. Download a fresh copy of EIA Table22.xls
2. Unhide all columns
3. Compare layout to sheet OILPROD. If the layout is the same, then copy the new data into sheet OILPROD.

5.2 Cumulative Production

It is unlikely that the cumulative production data will need to be updated very often. If a new source of cumulative production becomes available (e.g., a new USGS Assessment) you may wish to compare the existing data to the new data.

1. Compile new cumulative production data, and note year through
2. Copy new data into sheet USGSCUM, being careful to match the countries
3. In sheet OILCUM, move the formula in column T (year 1995) to the column matching the year-through date of your new cumulative production data. This is your new cumulative base year column. The other years are calculated by adding or subtracting annual production from the base year value. Copy the formulas in column S into column T and any other columns to the LEFT of your new cumulative base column.

5.3 Reserves

Copy and paste the new reserves data, taking care not to overwrite the formulas in column A or below row 132.

5.4 Model Base Year

Worksheet DRIVERS column AB contains the base year for each country. Change this column for countries where you wish to roll the base year forward. Some countries that do not currently produce have a base year of 2010, or other future year.

6 DATA SOURCES

6.1 Annual Production

The primary source of annual crude oil and condensate production is EIA International Energy Annual 2003 Table 2.2. These data area available in the Excel spreadsheet table22.xls downloaded from the EIA Web site. Canadian oil sands production data are from Canadian Association of Petroleum Producers (CAPP) statistics compiled by EEA from the CAPP Web site and CAPP publications. Annual data are reported beginning in 1980, the first year of data in the EIA tables.

6.2 Cumulative Production

International (non-U.S.) cumulative crude oil, condensate, and NGLs production are from USGS 2000 World Assessment. United States data are from EEA estimates, as the USGS U.S. cumulative production data do not separate NGLs from oil. Cumulative production data are on an end of year 1995 basis.

The sum of annual oil production through 1995 is used in place of the USGS cumulative production for countries where the sum of annual figure is greater than the USGS figure (e.g., France). The USGS Assessment documentation is unclear about the completeness of the cumulative production data.

A cumulative production time series was developed by adding or subtracting annual production from the year-end 1995 cumulative production figure.

6.3 Proved Reserves

Proved reserves are from the EIA spreadsheet reserves.xls, downloaded from the EIA Web site. The original data source is The Oil and Gas Journal. Reserves statistics are presented as of January of each year.
Canada and World Total reserves were adjusted by EEA to remove the Canadian oil sands reserves beginning in 2003. The oil sands reserves are documented in the table footnotes.

6.4 Undiscovered Resource - New Fields

USGS 2000 World Assessment.

6.5 Reserve Growth

USGS 2000 World Assessment, modified by EEA.

6.6 Annual Oil Well Completions

World Oil Magazine.

6.7 Annual Number of Operating Oil Wells

World Oil Magazine.

7 EQUATIONS FOR SAGE MODEL

The World Oil Model is a spreadsheet model that takes the long-run crude oil supply curves from WAU plus historical production and reserve data and produces a forecast of annual crude oil production to 2100 by country as a function of oil price. The model is based on a "Hubbert" or "Logistic" curve concept but modifies that concept to account for the crude oil supply curve economics and how the price of oil could affect the "shape" of the curve (that is, higher oil price will accelerate oil exploration and skew the Hubert production curve to the left.) The model also calculates reserves, reserve additions, new oil wells drilled and the number of operating oil wells as additional outputs.

The intent behind building the World Oil Model was to test out data and algorithms that could be used in SAGE to represent oil production for non-OPEC regions. The World Oil Model was built at a country level because there are differences in the amount and quality of the data for each country. The country-level structure in the model will allow the underlying data to be kept in its original format and will permit aggregations into regions using current (or possible future changes to) SAGE region definitions. We expect that the SAGE implementation will be at the region level and describe here a way to aggregate the country-level data into initial (that is values for the base year) regional input parameters for SAGE.

The proposed working concept of how this could be implemented into SAGE is that a preprocessor would take initial parameters (and then results from each run period) and estimate cumulative production for each region and the last period's production rate. Based on those parameters the preprocessor would calculate all the needed coefficients to estimate production in the current SAGE period as a function of oil price.

Because the relationships are nonlinear there is no practical way to put them directly into the SAGE solver. For this reason, we assume that the preprocessor would create "supply steps" for million barrels per day of production at say, $20, $25, $30, $35, $40, etc. per barrel. The SAGE model would then solve for conventional oil production in non-OPEC regions using that period's supply curve. Based on period X results, the preprocessor would then set up the curves for period X+1.

The user of SAGE would be able to easily change inputs for the resource base size, technology drivers and "curve shape" parameters to set up alternative cases within SAGE.

7.1 Algorithms and Equations for SAGE

The three equations that need to put into SAGE preprocessor are contained in the boxes in this section. The relevant algorithms and parameters are discussed below.

Setup - initial values set once for each country:
The oil supply curve that is computed in the WAU model is represented in WOLM and SAGE as a nonlinear function with six input coefficients:

prc1 = price at first point on curve ($20)
prc1 = price at second point on curve ($50)
prc3 = price at third point on curve ($100)
rbf1 = portion resource base economic at first price point
rbf2 = portion of resource base economic at second price point
rbf3 = portion of resource base economic at third price point

These three points on the supply curve are used to develop a continuous equation that gives the economic resource base (as a fraction) as a function of oil price. The coefficients of that equation are defined as:

a3pt = rbf3 - rbf1
b3pt = LOG((rbf2-rbf1)/a3pt)/LOG((prc2-prc1)/(prc3-prc1))

The supply curve function that finds the economic resource as a function of price (variable "price") is:

SCF = rbf1 + a3pt*((price-prc1)/(prc3-prc1))**b3pt

The result SCF is a fraction of the entire resource base. The resource in million barrels base is found by multiplying the fraction economic times the resource base size (RB).

RBL1= RB*SCF

In the WOLM the resource base for the current year is based on a running average of prices up to the year before the current year. Therefore, the resource base lagged one year (RBL1) is the relevant variable in the production algorithm.

Annual production – calculated for each year or period:

Variables:

PRICEL1	= PRICE(t-1) is prior period price
PL1	= Prod(t-1) is prior period production
CPL1	= CP(t-1) is prior period cumulative production

Production can be expressed in a single equation:

P(t) = (CPL1+PL1)*(PL1/(CPL1*(CPL1-(rbf1 + a3pt*((PRICEL1-prc1)/(prc3-prc1))^b3pt)*RB))*((CPL1+PL1)-(rbf1 + a3pt*((PRICEL1-prc1)/(prc3-prc1))^b3pt)*RB))

For application within a five-year SAGE period, this equation can be executed for each year in a period and the annual production values summed into the period production.

Inputs parameters for SAGE can be derived directly from WOLM. Production and resource base can be added up directly to obtain regional sums for input into SAGE. However, the supply curve parameters must be weighted by the resource base in each country to arrive at the correct regional values (for rbf1, rbf2 and rbf3).

Derivation of annual production function:
The "single" production equation shown in the box above combines the supply curve function with the Hubbert equation. The basic Hubert or Logistic equation is:

P(i)/C = b + a*C

where:

i = year or other period
P(i) = production for period
C = cumulative production to beginning of period
a = slope for period
a = PL1/(CPL1*(CPL1-RBL1))
b = intercept for period
RBL1 = prior period resource base (defined by lagged oil price)
SCFL1 = prior period supply curve function
SCFL1 = rbf1 + a1*((PRICEL1-prc1)/(prc3-prc1))**b1
RBL1 = SCFL1 * RB
b = -a*RBL1
b = -a*(rbf1 + a1*((PRICEL1-prc1)/(prc3-prc1))**b1)*RB

multiply by C and make several substitutions:
P(i) = C*(b + a*C)
P(i) = C*(-a*RBL1 + a*C)
P(i) = C*a*(C - RBL1)
P(i) = C*(PL1/(CPL1*(CPL1-RBL1))*(C-RBL1)

After substituting for RBL1, the single-equation function for production as a function of lagged oil price becomes:
P(i) = C*(PL1/(CPL1*(CPL1-(rbf1 +
a1*((PRICEL1-prc1)/(prc3-prc1))**b1)*RB))
(C-(rbf1 + a1((PRICEL1-prc1)/(prc3-prc1))**b1)*RB))

Shape Adjustment (Production Acceleration)
Two important features of the Hubbert or Logistic curve is that peak production occurs when cumulative production is near half the resource base and production is symmetric around the peak. The WOLM contains algorithms that allow the user to change the shape of the Hubbert

curve to accelerate production when prices are high. This has the effect of skewing the production curve to the left. This shape multiplier in WOLM is calculated as:

$$SM_{(t)=} MAX(MIN(MAX(0,PRICE-Parm1)*Parm2,SM_{(t-1)} +0.005),SM_{(t-1)} -0.005)$$

Where:
Parm1 = the threshold price above which the shape adjustment is applied ($25)
Parm2 = shaping coefficient (0.002)

In WOLM the variable SM changes production by adjusting the Hubbert curve intercept (variable “a” above) by this fractional amount. For example, with values of $25 for Parm1 and 0.002 for Parm2, a $50 price of oil would create a value for MS of 0.05. However, to avoid unrealistic jumps in production, the value of MS in WOLM may not change by more than 0.005 from the prior year value. Note that because shape effect accumulates from one year to the next (because the production in year *t* is used to determine the equation coefficients for the year *t+1*), the difference from last year's shape multiplier is used to adjust the production value for any year.

$$P(i)\ \textit{after shape adjustment} = P(i) * (SM_{(t)} - SM_{(t-1)})$$

Option to Flattened Production Curve
The Hubbert or Logistic curves can tend to have sharp peaks, followed by steep production declines. It may be desirable for certain regions or types of oil production to represent a production track with a flat peak that continues for a period of time. The easiest way to represent this mathematically is by setting a maximum rate (as an absolute value or as a percent of the economic resource base) that overrides the value of the production equation. This is illustrated in Figure 7-1 which shows the conventional Hubbert curve as a solid blue line and the flattened curve as the red curve with white squares. The latter curve is computed by taking the lesser of the value from the Hubbert curve or 50.

If the conventional Hubbert Curve is written as:

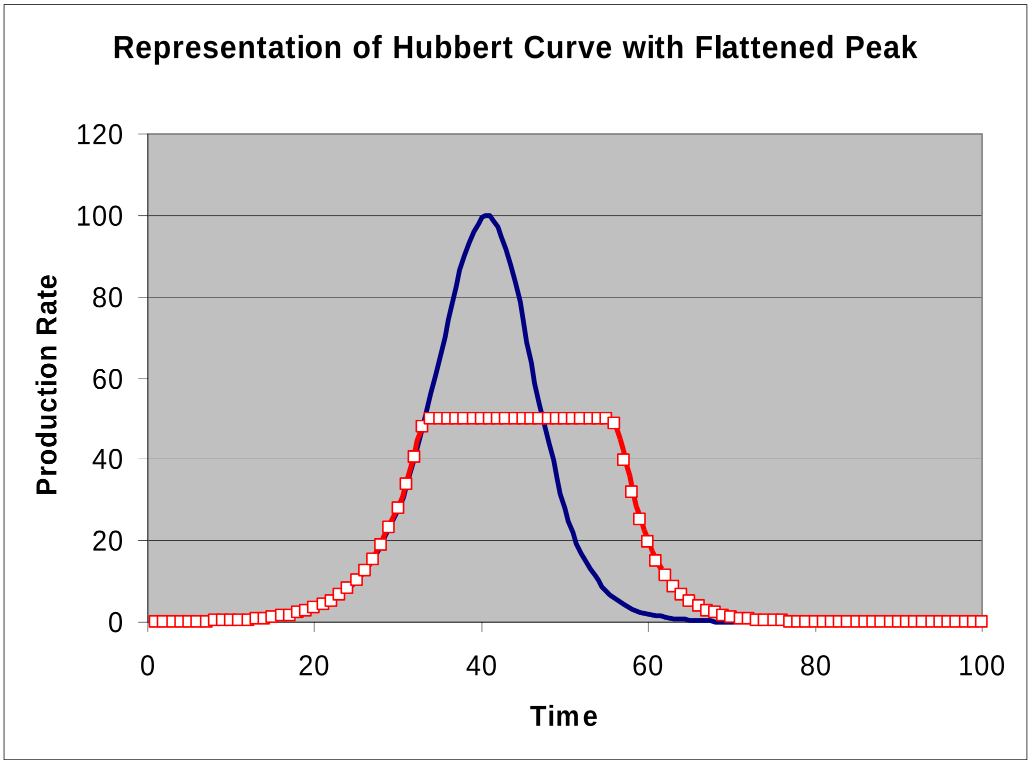
$$P(i) = b*C + a*C^2$$

Then the flattened curve with a plateau at the value of   “F” can be written as:

$$P(i) = MIN (b*C + a*C^2 , F)$$

Where b and a are the coefficients and C represents cumulative production.

Figure 7-1 Hubbert Curve with Flat Peak



8 APPENDIX A - VBA SOURCE CODE

```
Sub WorldOil1()
'
'  WorldOil1 Macro
' loop countries, calc, append results in sheet output
'
' Keyboard Shortcut: Ctrl+Shift+A
'
' Application.Goto Reference:="WorldOil1"

' Copyright Energy and Environmental Analysis, Inc. 2006
' programmer: Peter Springer 3/14/2006

 Application.ScreenUpdating = False
 Application.ErrorCheckingOptions.BackgroundChecking = False
 Application.Calculation = xlCalculationManual

Dim maxrows As Long
Dim num_countries As Long
Dim calc_row_offset As Long
Dim process As String
Dim counter As Long
Dim i As Long
Dim k As Long
Dim k1 As Long
Dim k2 As Long
Dim RBv As Variant
Dim RB As Double
Dim CPv As Variant
Dim CP As Double
Dim Prodv As Variant
Dim Prod As Double
Dim RURv As Variant
Dim RUR As Double
Dim OilWellsv As Variant
Dim OilWells As Double
Dim OperWellsv As Variant
Dim OperWells As Double
Dim PrintMe As String

' Clear Output Range
   Sheets("Output").Select
   Range("dataout").Select
   Selection.ClearContents

' initialize local variables
   counter = 0
   i = 0
   k = 0
   k1 = 0
   k2 = 0

   Sheets("Calc").Select
   Range("conum").Select
   Sheets("Calc").Range("conum") = 1
```

```
'-----------------------------------------------------------------------------
' read the maximum (last) row to process from input data area
   maxrows = Sheets("drivers").Range("number_of_years").Value
   num_countries = Sheets("drivers").Range("num_countries").Value
   calc_row_offset = Sheets("calc").Range("calc_row_offset").Value
   PrintMe = Sheets("drivers").Range("printme").Value

   For i = 1 To num_countries

' write row index in cell conum and recalc
      Sheets("Calc").Range("conum") = i
      Application.ScreenUpdating = True
      Calculate
      Application.ScreenUpdating = False

' check for process country Y/N
      process = Sheets("calc").Range("process").Value

      If process = "Y" Then
         counter = counter + 1

' check for printout switch
         If PrintMe = "Y" Then
            ActiveWindow.SelectedSheets.PrintOut Copies:=1, Collate:=True
         End If

'-----------------------------------------------------------------------------
' write results to the output sheet
         Sheets("Output").Select
         For k = 1 To maxrows
            k1 = k + (counter - 1) * maxrows
            k2 = k + calc_row_offset
            Range("dataout").Cells(k1, 1) = Worksheets("Calc").Range("C1").Value   ' conum
            Range("dataout").Cells(k1, 2) = Worksheets("Calc").Range("C2").Value   ' country
            Range("dataout").Cells(k1, 3) = Worksheets("Calc").Range("C3").Value   ' ieo region
            Range("dataout").Cells(k1, 4) = Worksheets("Calc").Range("C4").Value   ' usgs region
            Range("dataout").Cells(k1, 5) = Worksheets("Calc").Cells(k2, 1).Value  ' year
            Range("dataout").Cells(k1, 6) = Worksheets("Calc").Cells(k2, 2).Value  ' price

            RBv = Worksheets("Calc").Cells(k2, 4).Value
            RB = IIf(IsNumeric(RBv), RBv, 0)

            CPv = Worksheets("Calc").Cells(k2, 5).Value
            CP = IIf(IsNumeric(CPv), CPv, 0)

            Prodv = Worksheets("Calc").Cells(k2, 6).Value
            Prod = IIf(IsNumeric(Prodv), Prodv, 0)

            RURv = Worksheets("Calc").Cells(k2, 16).Value
            RUR = IIf(IsNumeric(RURv), RURv, 0)

            OilWellsv = Worksheets("Calc").Cells(k2, 18).Value
            OilWells = IIf(IsNumeric(OilWellsv), OilWellsv, 0)

            OperWellsv = Worksheets("Calc").Cells(k2, 19).Value
            OperWells = IIf(IsNumeric(OperWellsv), OperWellsv, 0)

            Range("dataout").Cells(k1, 7) = RB  ' RB
            Range("dataout").Cells(k1, 8) = CP  ' cumprod
            Range("dataout").Cells(k1, 9) = Prod ' annprod
            Range("dataout").Cells(k1, 10) = RUR ' reserves
            Range("dataout").Cells(k1, 11) = OilWells
            Range("dataout").Cells(k1, 12) = OperWells


            Sheets("Calc").Select
         Next k
      End If

' update World Total single point forecast values in sheet WorldPivot
```

```
      If i = 116 Then
         Sheets("WorldPivot").Select
         For k = 1 To maxrows
            k2 = k + calc_row_offset
            Range("SinglePoint").Cells(k, 1) = Worksheets("Calc").Cells(k2, 5).Value
            Range("SinglePoint").Cells(k, 2) = Worksheets("Calc").Cells(k2, 6).Value
         Next k
      End If
   Next i


'------------------------------------------------------------------------------
' refresh pivottable reports
  Sheets("WorldPivot").Select
  ActiveSheet.PivotTables("PivotTable1").RefreshTable

  Sheets("RegionPivot").Select
  ActiveSheet.PivotTables("PivotTable1").RefreshTable

  Sheets("TabE4").Select
  ActiveSheet.PivotTables("PivotTable1").RefreshTable    ' oil prod forecast
  ActiveSheet.PivotTables("PivotTable2").RefreshTable    ' plant liquids 2002
  ActiveSheet.PivotTables("PivotTable3").RefreshTable    ' refinery gain 2002
  ActiveSheet.PivotTables("PivotTable4").RefreshTable    ' other 2002

'------------------------------------------------------------------------------
    Sheets("Calc").Select
    Range("A1").Select
    Application.ScreenUpdating = True
    Application.ErrorCheckingOptions.BackgroundChecking = True
    Application.Calculation = xlCalculationAutomatic

End Sub
```