ANNEX E

THE $^{137}$Cs TECHNIQUE

$^{137}$Cs USE IN ESTIMATING SOIL EROSION:
A HISTORY

or

HOW DID WE GET HERE?

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Transcription of the transparencies presented by Mr. Ritchie in the RCM
OUTLINE

• INTERESTED IN EROSION

• HISTORY ON THE USE RADIONUCLIDES TO MEASUREMENT EROSION WITH EMPHASIS ON $^{137}$Cs

• GENERAL DISCUSSION OF THE DIFFERENT TECHNIQUES FOR USING $^{137}$Cs FOR EROSION MEASUREMENTS

SOIL EROSION

• NATURAL PROCESS
  • WORLD-WIDE PROBLEM
  • ACCELERATED BY MAN
  • MANY STUDIES ON AMOUNT AND COST

• MEASUREMENT
  • FIELD MEASUREMENTS
    • SURVEYS, PINS, ETC
    • FIELD PLOTS
    • TRACERS
    • STREAM DATA
    • RESERVOIR DATA
    • REMOTE SENSING
    • DIFFICULT, TIME CONSUMING

• MODEL ESTIMATES
  • USLE (EMPIRICAL)
  • RUSLE (REVISED USLE)
  • SLEMA
  • WEPP (PROCESS BASED)
  • OTHERS (CREAMS, ANSWERS, AGNPS, ETC)
  • ONLY GIVE ESTIMATES
  • DO NOT SHOW SPATIAL PATTERNS

NEEDS INFORMATION ON SOIL EROSION

• ESTIMATE SOIL LOSS
• UNDERSTAND PRODUCTIVITY LOSS
• UNDERSTAND PRODUCTIVITY DIFFERENCES
• DOWNSTREAM OFFSITE DAMAGE
• MANAGE WATER QUALITY PROBLEMS
• PLAN CONSERVATION PRACTICES
• INVENTORY/ASSESS REGIONAL SOIL LOSS
• IMPLEMENT NATIONAL POLICY
• PROVIDE BASIS FOR COST SHARING
• PLAN WATER SYSTEMS
• DETERMINE EFFECTS ON NAVIGATION
• OTHERS

• NEED DATA ON SPATIAL PATTERNS
  • PRECISION FARMING
NEED A SIMPLE METHOD TO GET UNBIASED MEASUREMENTS OF ACTUAL SOIL EROSION THAT MUST BE CAPABLE OF SHOWING SPATIAL PATTERNS OF EROSION AND DEPOSITION WITHIN FIELDS.

METHOD NEEDS TO BE CAPABLE OF MAKING THESE MEASUREMENTS AT LOCATIONS:

- WHERE OTHER EROSION DATA ARE NOT AVAILABLE
- WHERE LONG-TERM EXPERIMENT CAN NOT BE ESTABLISHED
- TRAINING SHOULD BE MINIMAL

WHY USE $^{137}$Cs

- PHYSICAL PROPERTIES
  - UNIQUE ELEMENT
  - SUPPLY DECREASING
  - EASILY MEASURED
    - SPECIALIZED EQUIPMENT
  - UNIFORMLY DISTRIBUTED
    - NEED LOCAL INFORMATION
    - REACTOR RELEASES

- CHEMICAL PROPERTIES
  - STRONGLY ADSORBED TO FINES
    - PARTICLE SIZE DISTRIBUTION
  - LOW SOLUBILITY
    - UNIQUE CONDITIONS (ACID)
  - LIMITED UPTAKE BY PLANTS

WITH LIMITED CHEMICAL AND BIOLOGICAL MOVEMENT THEREFORE MOVEMENT IS BASICALLY BY PHYSICAL PROCESSES: WATER AND WIND

ASSUMPTIONS FOR EROSIONS STUDIES

- ONCE $^{137}$Cs REACHES THE SOIL SURFACE, IT IS FIRMLY ADSORBED TO THE FINE SOIL PARTICLES; THEREFORE ANY MOVEMENT IN THE ENVIRONMENT IS ALMOST EXCLUSIVELY ASSOCIATED WITH SOIL PARTICLE MOVEMENT.
• $^{137}\text{Cs}$ was uniformly distribute initially, thus any changes in the spatial distribution will be due soil movement over the time period. (Chernobyl creates problem)

• $^{137}\text{Cs}$ distribution on the landscape can be used to estimate the spatial variation in erosion - areas of net erosion as well as areas of deposition within the field.

• Can be used to estimate long-term erosion (late 1970's last significant fallout $^{137}\text{Cs}$ - except Chernobyl)

• 30 year half-life means that it will be detectable for years in the future
BASIS OF THE CESIUM-137 TECHNIQUE

Cesium-137 in Atmosphere

Deposition with Precipitation

Transport with Eroded Particles

Lakes/Reservoirs

Deposition

Sample Collection

Ground Surface

Redeposition

Adsorption on Fines
ADVANTAGES OF $^{137}\text{Cs}$
(AND $^{210}\text{Pb}$)

- ESTIMATES REPRESENT ALL EROSION LOSS
- ESTIMATES REPRESENT LONG-TERM AVERAGE
- ESTIMATES ARE SITE SPECIFIC
- MINIMUM DISTURBANCE TO STUDY SITE
- ESTIMATES GIVES BOTH SPATIAL PATTERNS AND RATES OF EROSION/DEPOSITION
- ESTIMATES CAN BE MADE FROM A SINGLE VISIT TO THE SITE
- EASILY DETECTED

BACKGROUND

- BIBLIOGRAPHY OF PAPERS RELATED TO $^{137}\text{Cs}$ USE IN STUDIES OF EROSION AND SEDIMENT DEPOSITION
- EXPONENTIAL INCREASE IN PUBLICATIONS SINCE THE FIRST PUBLICATION IN 1960
- CURRENTLY ALMOST 1600 CITATIONS
- APPROXIMATELY 500 ARE RELATED TO EROSION MEASUREMENTS
- APPROXIMATELY 700 ARE RELATED TO SEDIMENT DEPOSITION MEASUREMENTS
- REMAINDER ARE RELATED TO THE CHEMICAL, PHYSICAL AND BIOLOGICAL PROPERTIES OF $^{137}\text{Cs}$ IN ENVIRONMENT

BACKGROUND

1960
R. MENZEL: TRANSPORT OF STRONTIUM-90 IN RUNOFF, SCIENCE 131:499- 500
- MEASURED LOSS OF FALLOUT $^{90}\text{Sr}$ FROM "STANDARD" EROSION PLOTS
- CONCLUDED THAT $^{90}\text{Sr}$ LOSS WAS GREATEST FROM THOSE PLOTS THAT HAD THE GREATEST SOIL LOSS

- MEASURED FALLOUT $^{90}$Sr IN SOIL AS A FUNCTION OF SLOPE AND CONCLUDED THE $^{90}$Sr LOSS FROM FIELDS WAS DUE TO EROSION


- ADDED RADIOACTIVITY
- CONCLUDED THAT RUNOFF WAS A FACTOR IN $^{85}$Sr AND $^{131}$I REMOVAL


- CONCLUDED THAT RUNOFF WAS A FACTOR IN $^{137}$Cs AND $^{90}$Sr LOSS

1964

S.I. AUERBACH, J.S. OLSON, H.D. WALLER LANDSCAPE INVESTIGATIONS USING CESIUM-137. NATURE 201: 761-764

- PAPER MOSTLY RELATED TO $^{137}$Cs IN VEGETATION BUT SUGGESTED THAT REMOVAL OF CESIUM BY PHYSICAL FACTORS

1965

A.S. ROGOWSKI AND T. TAMURA MOVEMENT OF $^{137}$Cs BY RUNOFF, EROSION AND INFILTRATION ON THE ALLUVIAL CAPTINA Silt Loam. HEALTH PHYSICS 11: 1333-1340

- FIRST OF THREE PAPER (1970)
- ADDED $^{137}$Cs TO PLOTS
- BASED ON 83 DAYS OF DATA
- MEASURED RUNOFF, SOIL LOSS AND $^{137}$Cs LOSS
- FOUND EXPONENTIAL RELATIONSHIP BETWEEN SOIL AND $^{137}$Cs LOSS

W.H. WISCHMEIER AND D.D. SMITH. PREDICTING RAINFALL EROSION LOSSES FOR CROPLAND EAST OF THE ROCKY MOUNTAINS. USDA AGRICULTURE HANDBOOK NO. 262

- UNIVERSAL SOIL LOSS EQUATION (USLE) BASED ON MEASURED DATA

1968

R.C. DAHLMAN AND S.I. AUERBACH PRELIMINARY ESTIMATION OF EROSION AND RADIOCESIUM REDISTRIBUTION IN FESCUE MEADOW. ORNL-TM-2343. OAK RIDGE NATIONAL LABORATORY

- ADDED $^{137}$Cs TO GRASS PLOTS
- MEASURED RUNOFF, SOIL LOSS AND $^{137}$Cs LOSS
FOUND EXPONENTIAL RELATIONSHIP

1970


- ADDED $^{137}$Cs
- FOLLOW UP TO 1965 PAPER
- BASED ON TWO (2) YEARS DATA
- SAME CONCLUSIONS


- DIFFERENCE IN DISTRIBUTION OF $^{137}$Cs BETWEEN VEGETATION TYPES WAS DUE TO SOIL LOSS FROM THE LANDSCAPE TO SOIL LOSS FROM THE LANDSCAPE

V.T. BOWEN, V.E. NOSHGIN, H.L. VOLCHOK, CAN LAND RUN-OFF BE A MAJOR VECTOR OF FALLOUT TO THE OCEAN. HASL-2179 HEALTH AND SAFETY LAB

- RESPONDING TO TALK BY ANDERSON AT AGU
- CONCLUDED THAT RIVER RUNOFF WAS NOT A MAJOR VECTOR FOR FALLOUT MOVEMENT TO THE OCEAN.
- HOWEVER ALSO CONCLUDE THAT FALLOUT IN RIVERS WAS "NOT INSIGNIFICANT"

F. HAGHIRI, FATE OF STRONTIUM-90 IN SOILS, PLANTS AND WATER OHIO REPORT 55:74-77

- ADDED $^{90}$Sr
- CONCLUDED $^{90}$Sr LOSS WAS DIRECTLY RELATED TO THE QUALITY (EROSION) OF THE WATER LEAVING THE PLOT

1972

RITCHIE, J.C., J.R. MCHENRY, A.C. GILL THE DISTRIBUTION OF CS-137 IN LITTER AND THE UPPER 10 CENTIMETERS OF SOIL UNDER DIFFERENT VEGETATION TYPES IN NORTHERN MISSISSIPPI, HEALTH PHYS. 22:197-198

CONCLUDED ERODED SOIL HAS LESS $^{137}$Cs

- USE MEASUREMENTS OF FALLOUT $^{137}$Cs LEFT IN THE SOIL TO ESTIMATE SOIL LOSS
- FOUND EXPONENTIAL RELATIONSHIP

RITCHIE, J.C., J.R. MCCHENRY, A.C. GILL, AND P.H. HAWKS, DISTRIBUTION OF CS-137 IN A SMALL WATERSHED IN NORTHERN MISSISSIPPI, USAEC CONF-710501 PP. 129-133

- WATERSHED BALANCE FOR $^{137}$Cs

1974


- USE MEASUREMENTS OF FALLOUT $^{137}$Cs LEFT IN THE SOIL TO ESTIMATE SOIL LOSS
- FOUND EXPONENTIAL RELATIONSHIP
- ADDED DATA FROM OTHER STUDIES (1975) AND FOUND THAT IT ALL FIT THE SAME EXPONENTIAL RELATIONSHIP

RITCHIE, J.C., J.R. MCCHENRY, A.C. GILL FALLOUT CS-137 IN THE SOILS AND SEDIMENTS OF THREE SMALL WATERSHEDS, ECOLOGY 55:887-890

- WATERSHED BALANCES FOR $^{137}$Cs


- LOSS OF $^{90}$Sr FROM WATERSHED IS RELATED TO SHEET EROSION BUT NOT GULLY AND RILL EROSION

1975-1979

- MccALLAN AND ROSE PROPOSED USING TO MEASURE EROSION IN A BASIN IN AUSTRALIA
- WISE PUBLISHED A REVIEW PAPER IN ENGLAND ON THE USE $^{137}$Cs AND $^{210}$Pb TO MEASURE DENUINATION RATES
- MCCHENRY AND RITCHIE USED $^{137}$Cs DISTRIBUTION IN AN AGRICULTURAL FIELD TO SHOW THAT WHILE EROSION WAS OCCURRING IN THE FIELD, $^{137}$Cs COULD BE USED TO SHOW THAT MOST OF THE MATERIAL WAS BEING REDEPOSITED WITHIN THE FIELD.
- WALLING ET AL. USED MAGNETIC MEASUREMENTS TO DETERMINE SOURCE OF EROSION MATERIAL
SPURGE ET AL. FOUND $^{137}$Cs AND Pu LOSS WAS RELATED TO EROSION

1980's (GROUPS ACTIVE IN $^{137}$Cs /EROSION RESEARCH)

AUSTRALIA (1981)
G.L. Elliott, R.J. Loughran, B.L. Campbell

CANADA (1982)
D.J. Pennock, E. de Jong, R.G. Kachanoski, J.J. Kiss, L.W. Martz

GREAT BRITAIN (1984)
D.E. Walling, T.A. Quine, X. Zhang, Q. He

UNITED STATES
J.C. Ritchie, J.R. McHenry, J.C. Lance, S.C. McIntyre

IAEA ACTIVITIES

ADVISORY GROUP MEETING, 26-19 APRIL 1993
"USE OF NUCLEAR TECHNIQUES IN STUDYING SOIL EROSION AND SEDIMENTATION"

CONSULTANTS MEETING, 13-16 NOVEMBER 1995
"THE USE OF ISOTOPES IN STUDIES ON SOIL EROSION"

1ST RESEARCH COORDINATION MEETING, 11-15 NOVEMBER 1996

TYPES OF STUDIES

- EMPIRICAL EQUATIONS
- PROPORTIONAL MODELS
- MASS ACCOUNTING/THEORETICAL MODELS
- SEDIMENT ACCUMULATION IN LAKES

EMPIRICAL STUDIES

- SIMULTANEOUS MEASUREMENT OF SOIL LOSS AND $^{137}$Cs (RADIONUCLIDE) LOSS FROM EROSION PLOTS


R.C. Dahiman and S.I. Auerbach. 1968. ORNL-TM-2343.

Health Phys. 11:1333-1340.
EMPIRICAL STUDIES

• CORRELATION BETWEEN SOIL LOSS MEASURED FROM PLOTS AND THE REDUCTION OF $^{137}$Cs IN THESE PLOTS


EMPIRICAL STUDIES

• CORRELATION BETWEEN ESTIMATES OF SOIL LOSS FROM FIELDS AND THE REDUCTION OF $^{137}$Cs IN THE SOILS OF THESE FIELDS

Agronomy Abstracts p. 129.
J. Soil Water Conserv. 30:283-286.


EMPIRICAL STUDIES

• ASSUMPTION

- SOIL LOSS EQUATED TO $^{137}$Cs LOSS

• PROMISE

- SIMPLE IN CONCEPT
- GOOD AS THE DATA DOMAIN
- EARLY STUDIES SHOWED IT HELPED UNDERSTAND FACTORS INVOLVED

• PROBLEMS

- LIMITED BY DATA DOMAIN
- SPATIAL/TEMPORAL LIMITATIONS
- NEEDS LOCAL CALIBRATION APPLICABLE TO AN AREA NOT A POINT THUS SAME LIMITATIONS AS WITH MATHEMATICAL MODELS (RUSLE)
- MISUSED
• CONCLUSION

- HELPED TO UNDERSTAND SOME OF THE BASIC FUNDAMENTALS
- CAN USE WITH GOOD DATA SET LIKE ELLIOTT ET AL., HAS FOR AUSTRALIA
- USE WITH CARE IF IT IS GOING TO BE PART OF THIS CRP

PROPORTIONAL MODELS

• SOIL LOSS (GAIN) IS PROPORTION TO THE $^{137}$Cs LOSS (GAIN) IN MEASURED PROFILES (MODIFIED BY SOIL/ENVIRONMENTAL CONDITIONS i.e. BULK DENSITY, TIME, PLOW DEPTH, etc)

  Many Others

•ASSUMPTION

•SOIL AND $^{137}$Cs LOSS PROPORTIONAL
•UNIFORM SOIL LOSS FROM PROFILE
•REFERENCE VALUE OF $^{137}$Cs

EQUATION FORM

•MODIFIED EMPIRICAL (i.e. BULK DENSITY, PLOW DEPTH, TIME, DECAY)
•KACHANOSKI (1987) VERIFICATION

PROMISE

• SIMPLE APPROACH
• DATA USUALLY READILY MEASURABLE

PROBLEMS

•UNIFORM DISTRIBUTION IN PROFILE AND IN TIME AND SPACE
•UNIFORM SOIL LOSS WITH TIME

CONCLUSION

•TENDS TO OVERESTIMATES SOIL LOSS
•CARE SHOULD BE USED

THEORETICAL MODELS/MASS ACCOUNTING

WALLING AND QUINE HAVE DEFINED THE THEORETICAL MODELS AS "THE AGGREGATE EFFECT OF ALL REDISTRIBUTIONS PROCESSES OPERATING OVER THE
PERIOD SINCE THE INITIATION OF ATMOSPHERIC FALLOUT TO ESTABLISH SITE SPECIFIC CALIBRATION RELATIONSHIPS”


MASS ACCOUNTING/THEORETICAL MODELS

ASSUMPTION

SOIL AND $^{137}$Cs LOSS CAN BE UNDERSTOOD BY INCORPORATING THE SIGNIFICANT FACTORS INVOLVED IN $^{137}$Cs MOVEMENT

EQUATION FORM

MODIFIED PROPORTIONAL TO ACCOUNT FOR SIGNIFICANT FACTORS AND TIME SCALES
TIME SCALE USUALLY A TIED TO TILLAGE

PROMISE

PROVIDES A BETTER DESCRIPTION OF THE PROCESSES INVOLVED

PROBLEMS

GETTING ALL THE DATA NEEDED TO RUN A "PROCESS" BASED MODEL WHICH REQUIRES MANY INPUTS
GREATER CHANCE FOR ERROR

CONCLUSION

CARE SHOULD BE USED
LOSS = -31.19 T/HA/YR
GAIN = 22.73 T/HA/YR
NET = -8.82 T/HA/YR
THE Cs-137 TECHNIQUE FOR SOIL EROSION ASSESSMENT

PRINCIPLES AND LIMITATIONS

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I) ADVANTAGES AND DISADVANTAGES

II) ASSUMPTIONS AND REQUIREMENTS

III) PROBLEMS AND UNCERTAINTIES
I - KEY ADVANTAGES AND DISADVANTAGES

(To be considered in the light of the general problems of erosion monitoring/assessment)

A - ADVANTAGES

- Retrospective assessment of medium-term rates of soil redistribution
- Single site visit, results available relatively quickly
- Field sampling and laboratory measurement relatively easy
- No significant disturbance to study area
- Resulting estimates of soil redistribution rates are *medium-term* averages and less influenced by extreme events
- Provides information on both erosion and deposition and therefore net rates of sediment export
- Results reflect the effects of all erosive processes
- Provides spatially distributed point estimates of soil redistribution rates which permit investigation of spatial patterns
- Compatible with recent developments in distributed modelling of soil erosion and sediment yield

B - DISADVANTAGES

* Needs costly gamma counting equipment
* Primarily suited to small-scale studies
* Effectively limited to documentation of sheet and rill erosion and general surface lowering
* An indirect approach depending on the link between soil redistribution and Cs-137 redistribution

II - KEY ASSUMPTIONS AND REQUIREMENTS

APPROACHES:

1) Redistribution of original Cs-137 input
2) Redistribution between two surveys
A - INPUTS

1) CAESIUM- 137 INPUTS
   (a) Adequate inventories
   (b) Chernobyl complications

2) SPATIAL UNIFORMITY OF INPUTS AT LOCAL SCALE

3) ESTABLISHMENT OF REFERENCE INVENTORIES
   (a) Use of undisturbed reference sites
       (b) Sampling considerations

B - BEHAVIOUR OF RADIOCESIUM IN THE SOIL PROFILE

1) RAPID AND STRONG FIXATION

2) SUBSEQUENT REDISTRIBUTION OCCURS IN ASSOCIATION WITH
   SOIL/SEDIMENT PARTICLES

3) REDISTRIBUTION OF Cs-137 IS INDICATIVE OF BULK SOIL
   REDISTRIBUTION (minimal particle size effect)

C - ESTIMATION OF SOIL REDISTRIBUTION RATES FROM Cs-137
   MEASUREMENTS

1) RATES OF SOIL REDISTRIBUTION CAN BE ESTIMATED FROM DEVIATION
   OF Cs- 137 INVENTORIES FROM REFERENCE INVENTORY

2) AVAILABILITY OF RELIABLE AND MEANINGFUL "CALIBRATION"
   RELATIONSHIPS

3) TRANSPORTABILITY OF EMPIRICAL "CALIBRATION" RELATIONSHIPS

4) GENERAL APPLICABILITY OF THEORETICAL "CALIBRATION"
   RELATIONSHIPS

III - KEY LIMITATIONS AND UNCERTAINTIES

A - LIMITATIONS

1) THE GLOBAL PATTERN OF Cs- 137 FALLOUT MAY PRECLUDE
   APPLICATION OF THE TECHNIQUE IN SOME AREAS OF THE GLOBE
2) CHERNOBYL INPUTS MAY COMPLICATE INTERPRETATION OF RESULTS WHERE THEY REPRESENT A SIGNIFICANT PROPORTION OF THE TOTAL INVENTORY

3) THE APPROACH MAY BE OF LIMITED APPLICABILITY OR VALUE UNDER SOME PHYSIOGRAPHIC CONDITIONS

4) ESTABLISHMENT OF THE REFERENCE INVENTORY MAY REQUIRE A CAREFULLY PLANNED SAMPLING STRATEGY

5) PREFERENTIAL MOBILITY OF Cs-137 IN RELATION TO GRAIN SIZE AND THE ORGANIC FRACTION WILL COMPLICATE INTERPRETATION OF Cs-137 DATA

6) THE APPROACH IS HEAVILY DEPENDENT ON THE EXISTENCE OF A RELIABLE AND MEANINGFUL "CALIBRATION" RELATIONSHIP

7) MEASUREMENT PRECISION AND SAMPLING VARIABILITY MAY LIMIT THE RESOLUTION OF THE APPROACH

8) COST AND AVAILABILITY OF Cs-137 MEASUREMENT FACILITIES

9) UPSCALING AND EXTRAPOLATION OF POINT MEASUREMENTS

B - UNCERTAINTIES

1) LOCAL SCALE VARIABILITY OF Cs-137 FALLOUT INPUTS

2) ESTABLISHMENT OF REFERENCE INVENTORIES

3) BEHAVIOUR OF Cs-137 IN THE SOIL PROFILE

4) INCORPORATION OF GRAIN SIZE AND ORGANIC FRACTION SELECTIVITY INTO THE INTERPRETATION OF Cs-137 DATA

5) DISCREPANCIES BETWEEN THEORETICAL AND EMPIRICAL "CALIBRATION" RELATIONSHIPS
   (a) Need for more empirical data
   (b) Need for more experimental data and information on fallout inputs to parameterize mass balance models

6) SCALE EFFECTS

7) OPTIMUM SAMPLING STRATEGY (cost-benefit)