Wasser und Ernährungssicherheit

Problemlagen und Reformoptionen

Waltina Scheumann und Andreas Kuck gilt mein herzlicher Dank für die anregende Kritik und die wertvollen Hinweise zum Manuskript.

I. Globale Ressourcen- verfügbarkeit und Datenlage

Seit den sechziger Jahren leistet die Bewässerungslandwirtschaft einen zunehmend wichtigen Beitrag zur globalen Nahrungsproduktion. Der aktuelle Beitrag liegt bei 42 Prozenttoptop, und Prognosen gehen davon aus, dass er in Zukunft noch weiter ansteigen wird.toptop Für die Wasserressourcen bedeutet dies, dass Oberflächengewässern und Grundwasser in steigendem Maße Frischwasser ("blaues Wasser") entzogen wird, das anderen Nutzern dann nicht mehr zur Verfügung steht. Jede Tonne Weizen benötigt zu ihrer Produktion 1 000 Tonnen Wasser. Heute kommen bereits 72 Prozent der weltweiten und 90 Prozent der Wasserressourcen in Entwicklungsländern der Bewässerungswirtschaft zugute. Angesichts der wachsenden Bevölkerung und der begrenzten globalen Wasserressourcen stimmen diese Zahlen nachdenklich.

Dem Regenfeldbau, bei dem das im Boden gebundene Wasser genutzt wird ("grünes Wasser") und auf dessen Basis aktuell rd. 58 Prozent der Nahrungsmittel produziert werden, wird in der Debatte um Wasserressourcen bei weitem nicht die gleiche Aufmerksamkeit entgegengebracht, obwohl er hier eigentlich von gleichrangiger Bedeutung sein müsste. Zwar kann "grünes Wasser" nicht anderweitig alloziiert werden, jedoch besitzt der Regenfeldbau einen Substitutionswert, denn jede Tonne Nahrung, die zusätzlich im Regenfeldbau produziert wird, spart potenziell 1 000 Tonnen Bewässerungswasser ein. Es ist deshalb von großem Interesse, die Zukunftspotenziale für den Regenfeldbau abzuschätzen, und neue Modellrechnungen zeigen, dass diese rein rechnerisch gesehen durchaus bedeutend sind.toptop Parallel hierzu muss sich aber auch die Bewässerungslandwirtschaft weiterentwickeln, wenn der zukünftige Bedarf an Nahrungsmitteln gedeckt werden soll.

Daten über den *Status quo* und technisches *Know-how* sind wichtig als Grundlage für die Identifizierung von Politiken, Möglichkeiten und Zielen einer nachhaltigen Ernährungs- und Bewässerungswirtschaft. Sowohl für die Ursachenanalyse als auch für die Entwicklung von Zukunftsstrategien ist jedoch darüber hinaus die Betrachtung der ökonomischen, sozialen und politischen Dimension essenziell. So ist es schon lange Konsens unter den Fachleuten, dass der Welthunger nicht in erster Linie ein Produktionsproblem ist, sondern dass die Hauptursachen die ungleiche Verteilung von Einkommen und politische Krisen sind. Deshalb kann dieses Problem auch nur unter Einbeziehung der sozioökonomischen und politischen Dimension gelöst werden. Diese Sicht wurde auch kürzlich wieder auf der *International Conference on Sustainable Food Security for all by 2020* vom 4. bis 6. September 2001 in Bonn bestätigt.toptop

Über die globalen Wasserressourcen wird aktuell jedoch noch auf eine andere Weise diskutiert. Häufig dominiert die Sichtweise von der absoluten Knappheit der Ressource.toptop Dabei spricht vieles dafür, dass Süßwasserressourcen global gesehen ähnlich wie Nahrungsmittel in ausreichender Menge vorhanden sind. Allerdings ist die Datenlage bis heute sehr unsicher, und die Angaben in Studien schwanken in Abhängigkeit von den jeweils getroffenen Grundannahmen um den Faktor 2-400. Bis heute ist es deshalb eine subjektive Einschätzungsfrage, ob Wasserressourcen insgesamt als knapp oder ausreichend angesehen werden. Die entscheidenden Unsicherheitsfaktoren bei den Prognosen sind die Entwicklung

der Bevölkerungszahlen (sie schwanken um 40 Prozent)toptop und die Annahmen über den zukünftigen Wasserbedarf pro Person (er schwankt um 100 Prozent).toptop Beide Faktoren hängen hochgradig von der wirtschaftlichen Gesamtentwicklung, von Politikmaßnahmen sowie der Entwicklung und Umsetzung technischer Möglichkeiten ab, die nicht vorhergesagt werden können. Sehr unterschiedliche Einschätzungen bestehen auch im Hinblick auf die Beurteilung der gegenwärtig verfügbaren Wasserressourcen, denn in vielen Ländern ist die Datenlage hierüber vollkommen unzureichend.toptop

Wie die oben genannten Zahlen zum Wasserverbrauch für die Ernährungssicherheit verdeutlichen, können das Hunger- und das Wasserproblem im Grunde nicht getrennt voneinander diskutiert werden, sie hängen unmittelbar zusammen. Wassernutzung in der Landwirtschaft ist immer auch Bodennutzung und umgekehrt.

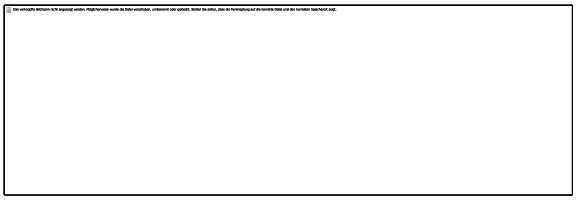
II. Wasserökonomische versus agrarökonomische Sichtweisen

Wasserökonomen gehen bei ihrer Statusanalyse von Wasserverbräuchen der einzelnen Wassersektoren (Haushalte, Industrie und Landwirtschaft) aus und setzen die Höhe der Wertschöpfung pro Volumeneinheit Wasser als Maßstab für eine effiziente Wassernutzung an. Da die Agrarproduktion eine viel geringere Wertschöpfung pro Volumeneinheit aufweist als der Industriesektor, plädieren viele Wasserökonomen für eine drastische Einschränkung der Bewässerungslandwirtschaft. Zielvorgabe ist, eine höhere Produktivität, z. B. in Form von Arbeitsplätzen pro Wassereinheit zu verträglichen Preisen, zu erreichen, nach dem Leitsatz: *more jobs per drop at reasonable cost*. Die Logik dieser Forderung besteht darin, dass Wasser in der Industrie einen höheren ökonomischen Wert besitzt und dass die Kapazität der Wirtschaft als Ganzes es erforderlich macht, Wasser dem ökonomisch produktivsten Sektor zuzuteilen.toptop

Agrarökonomen nehmen in der Regel eine andere Perspektive ein. Statt der Wasserproduktivität setzen sie die Flächenproduktivität als Maßstab an, d. h. den landwirtschaftlichen Ertrag, der pro Flächeneinheit erwirtschaftet wird. Da die Flächenproduktivität gerade in trockenen Ländern mit Bewässerung wesentlich höher ist als im Regenfeldbau, ist es aus agrarökonomischer Sicht Ziel, die Bewässerungslandwirtschaft, wo immer es möglich und rentabel ist, stärker auszuweiten. Dieser Ansatz wird von Turton nicht ganz zu Unrecht mit *more crop per drop at whatever cost* bezeichnet.

In Bezug auf den Wasserverbrauch bestehen für die Wassernutzer tatsächlich kaum Sparanreize. Der Gedanke, Wasser als landwirtschaftlichen Input - etwa wie Düngemittel und Pestizide - zu betrachten, ist für Landwirte zumeist fremd, denn auch das im Boden gebundene Wasser wird weltweit als freies Gut betrachtet. Um ihre Allokationsentscheidungen zu beeinflussen, d. h. einen relevanten Anteil an der Betriebskostenrechnung einzunehmen, müsste der Wasserpreis um ein Vielfaches steigen. Ein so hoher Preis würde zwar zum Sparen führen, er wäre politisch jedoch kaum durchsetzbar und mit gravierenden Nachteilen für den gesamten Landwirtschaftssektor verbunden.

Bis heute wird die Bereitstellung von Wasser mit Hilfe von Bewässerungssystemen in den meisten Ländern als Staatsaufgabe begriffen, für die als Gegenleistung die Landwirte Nahrungsmittel produzieren und hiermit einen Beitrag zur nationalen Selbstversorgung und volkswirtschaftlichen Entwicklung leisten. Auch wenn im Zuge der Privatisierungsdebatte vielerorts verstärkte Mitverantwortung der Bauern in Wassernutzergruppen eingefordert und auch umgesetzt wird, dominiert im landwirtschaftlichen Sektor doch nach wie vor das Selbstverständnis, nicht nur eine betriebswirtschaftlich, sondern auch eine volkswirtschaftlich



und gesellschaftlich wichtige Funktion zu erfüllen.

Die unterschiedlichen Perspektiven der Wasser- und Agrarökonomen lassen sich auch auf die öffentliche Debatte und die zuständigen Wasser- und Agrarinstitutionen in ariden Ländern übertragen. Die einzelnen Sektoren und Subsektoren erheben konkurrierende Ansprüche auf Frischwasserressourcen. Hierbei wird jedoch zumeist vergessen, dass es nur *einen* gemeinsamen Wasserkreislauf gibt und zwischen den beiden Sektoren Siedlungswasserwirtschaft und Bewässerungswirtschaft grundsätzliche Interdependenzen bestehen: Jeder Mensch benötigt im Jahr rd. 100 m³ Wasser für Trink- und Brauchwasserzwecke,toptop und gleichzeitig benötigt er 1 000 m³ Wasser pro Jahr, um sich mit Nahrungsmitteln zu versorgen.toptop Die Betonung des Konkurrenzverhältnisses zwischen den Sektoren ist für die Lösung des Wasserproblems kontraproduktiv. Statt dessen müsste es Ziel sein, die Wasseransprüche komplementär zu organisieren.

III. Ungleiche Verteilung und prinzipielle Lösungsmöglichkeiten

Zunächst soll jedoch auf die Verteilungsfrage näher eingegangen werden. Denn während vieles dafür spricht, dass global gesehen beide Ressourcen - Frischwasser und Nahrung - auch zukünftig in ausreichendem Maße vorhanden sind, ist ihre Verteilung über den Globus extrem ungleich. Die geringsten Wasserressourcen entfallen hierbei auf die Länder des Nahen Ostens und Nordafrikas sowie auf Länder in Subsahara-Afrika, die alle bereits unter drastischen Engpässen zu leiden haben. Neben der geografischen Lage sind hierfür hauptsächlich dem Bevölkerungs- und Wohlstandswachstum nicht angepasste Managementsysteme verantwortlich. Diese führen zu fortschreitenden Land- und Wasserverlusten in Form von Verwüstung, Versalzung und Verschmutzung beider Ressourcen.

Da besonders die Länder des Nahen Ostens ihre Wasserressourcen bereits weitgehend erschlossen haben und die weitere Erhöhung des Wasserdargebots sehr hohe Kosten verursacht,(grenzüberschreitendes Angebotsmanagement) und der Meerwasserentsalzung *(Angebotsmanagement)*, die Optionen für die Trinkwasserversorgung, bis heute aber nicht für große Bewässerungsflächen sind.')"(grenzüberschreitendes Angebotsmanagement) und der Meerwasserentsalzung *(Angebotsmanagement)*, die Optionen für die Trinkwasserversorgung, bis heute aber nicht für große Bewässerungsflächen sind.')" bleiben abgesehen von bevölkerungspolitischen Maßnahmen, die hier nicht betrachtet werden sollen, da sie nur indirekt beeinflussbar sind,toptop prinzipiell nur noch folgende Optionen, um den Versorgungsengpässen zu begegnen:

1. Import von *virtuellem Wasser* in Form von Getreideimporten aus Ländern mit Wasser- und Bodenreichtum *(sektorales Allokationsmanagement)*,

2. Stabilisierung oder Senkung der Nachfrage durch Sparen und Effizienzsteigerung bei vorhandenen Nutzungssystemen *(Endnutzereffizienz)*,

3. Reform und Reorganisation der Wasser- und Landnutzungssysteme *(Anpassungsmanagement)*.

Im Folgenden werden die erste und die dritte Strategie näher betrachtet. Die zweite Strategie wird nur kurz erwähnt, da hierüber umfangreiche Literatur existiert.

IV. Kann der Handel mit virtuellem Wasser das Wasserproblem lösen?

Die grundsätzliche Idee dieses Ansatzes besteht darin, das Wasserdefizit in ariden Ländern durch den Import von Getreide aus wasserreichen Ländern auszugleichen ("virtuelles Wasser")virtuellen Wassers wurde von A. Allan geprägt (Anm. 9).')"virtuellen Wassers wurde von A. Allan geprägt (Anm. 9).')". Aus globaler wasserökonomischer Sicht ist es für aride Länder sinnvoller, Nahrungsmittel zu importieren, als die knappen Wasserressourcen in die eigene, möglicherweise nicht rentable Produktion von Grundnahrungsmitteln zu investieren. Da zur Produktion einer Tonne Weizen tausend Tonnen Wasser benötigt werden, sprechen sowohl ökologische als auch ökonomische Gründe dafür, virtuelles Wasser in Form von Getreide *(soft option)* und nicht das Mengenäquivalent von tausendmal so viel Wasser *(hard option)* einzuführen.toptop

In der Tat zeigen Modellrechnungen von Rosegrant, dass dies eine Strategie ist, mit der beträchtliche Wasserressourcen eingespart werden könnten. Aus wasserökonomischer Sicht besteht das einzige Problem in der Finanzierung der Importe, die aus Exporterlösen der ariden Länder, d. h. aus der industriellen Produktion oder aus dem Verkauf von Rohstoffen (z. B. Öl), stammen müssten. Da die industrielle Produktion wassereffizienter ist als die Agrarproduktion, würden die Wasserressourcen auf diese Weise tatsächlich effizienter genutzt.

Aufgrund der Devisenarmut der meisten ariden Länder muss das tatsächliche Potenzial des Imports virtuellen Wassers allerdings als begrenzt angesehen werden. Nur wenige Länder weisen eine positive Zahlungsbilanz auf, diese ist jedoch Voraussetzung für eine entsprechende politische Strategie. Manche Wasserökonomen fordern daher von den USA und der EU, ihre Getreide- und Rindfleischüberschüsse wie bisher zu subventionieren, damit die Importe sich im Vergleich zur Eigenproduktion rechnen.toptop

Bei dieser Argumentation werden allerdings die Interessen derjenigen Länder nicht berücksichtigt, deren Entwicklung von der Agrarwirtschaft und von Agrarexporten abhängt. Zahlenmäßig ist dies die weitaus größere Gruppe von Ländern. Subventionierte Getreide- und Rindfleischpreise laufen den Interessen dieser, namentlich afrikanischer Länder diametral entgegen. Denn sie können zu solch niedrigen Preisen nicht produzieren und verlieren damit ihre Konkurrenzfähigkeit, d. h., ihre Marktchancen auf eigenen und auf Drittmärkten werden hierdurch untergraben. Teilweise bewirken die niedrigen Weltmarktpreise, dass die betreffenden Länder selbst Agrargüter importieren und damit ihre eigenen ländlichen Regionen marginalisieren. Sie verlieren hierdurch nicht nur zusätzlich wertvolle Devisen, sondern behindern ihre eigene Entwicklung tiefgreifend.toptop

Aber auch für Länder mit Marktchancen außerhalb der Agrargüterproduktion und größerem Devisenreichtum sprechen gute Gründe gegen ein zu starkes Einschlagen der *Virtuelles-Wasser-Strategie*. Sie würden sich hiermit zunehmend von den wasserreichen Ländern, überwiegend den Ländern des Nordens, abhängig machen und könnten Preismanipulationen oder anderen politisch-strategischen Überlegungen der Getreideexporteure nichts entgegensetzen. Aber noch ein anderes Argument spricht gegen die unbegrenzte Ausweitung einer *Virtuelles-Wasser-Strategie*: Sie führt zur kulturellen und ökologischen Uniformität der Ernährung und Kulturlandschaft. Vielfalt ist jedoch ein wichtiger Bestandteil der menschlichen Lebensqualität und auch von hoher Bedeutung für die Erhaltung der

genetischen Ressourcen landwirtschaftlicher Nutzpflanzen. In jedem Fall erscheint es daher sinnvoll, Süd/Süd-Getreideimporte verstärkt ins Auge zu fassen und diese zu diversifizieren. Voraussetzung ist auch hier der Abbau der Preissubventionen für die Agrarüberschüsse des Nordens.

Die Debatte um das Für und Wider von Getreideimporten als prioritäre Lösung des Wasserproblems wird nicht nur wegen der aufgeführten Argumente überflüssig. Sie wird rein faktisch derzeit vom Bevölkerungswachstum überholt. Denn jeder Vorteil, der mit einem bewussten Strategiewechsel geschaffen werden könnte, wird faktisch zeitgleich durch dieses Wachstum kompensiert.toptop So wird der Getreideimport auch ohne eine bewusste Strategie seine Bedeutung lediglich für diejenigen Länder beibehalten, die es sich leisten können. Jeweils sind jedoch gleichzeitig auch Eigenanstrengungen zur inländischen Agrarproduktion notwendig, um den Bedarf an Wasser und Nahrung befriedigen zu können.

Eines zeigt die hier geführte Diskussion dennoch: Es ist wichtig, Wasserknappheit nicht isoliert, sondern im Lichte der ökonomischen und gesellschaftlichen Gesamtentwicklung eines Landes zu betrachten. Der Engpass für die wirtschaftliche und industrielle Entwicklung wasserknapper Länder besteht nicht in der Wasserknappheit als solcher, sondern in ihrer mangelnden Kapazität, dieser Knappheit zu begegnen - also in einer *Knappheit zweiter Ordnung*.toptop

V. Effizienzsteigerung und Reorganisation der Wassernutzung

Diese Knappheit zweiter Ordnung kann auch als *mangelnde soziale Anpassungskapazität* bezeichnet werden.toptop Für die betroffenen Länder besteht die einzige Chance darin, ihre Wassernachfrage durch Effizienzsteigerung zu stabilisieren oder ihre Nutzungssysteme so zu überdenken und zu reorganisieren, dass hierdurch Wasserressourcen tatsächlich eingespart werden. Ob sie dazu in der Lage sind, hängt von ihrem Reformwillen und ihrer ökonomischen Kapazität, von ihrem intellektuellen Potenzial, der Funktionstüchtigkeit ihrer Institutionen und der Bewusstseinsbildung in der Öffentlichkeit ab.

Im Folgenden werden für zwei Problemlagen, zutreffend auf zwei Ländertypen, Konzepte für diesen Anpassungsprozess aufgezeigt. Hierbei geht es weniger um die Beschreibung der Konzepte als solche, denn diese sind keineswegs neu. Stattdessen geht es um die Frage, warum diese Konzepte nur punktuell und nicht flächenübergreifend umgesetzt werden, welches also die Hemmfaktoren für eine Institutionalisierung der Maßnahmen sind und wie sie abgebaut werden könnten.

Die gewählten Problemlagen betreffen zum einen das so genannte "blaue" und zum anderen das so genannte "grüne" Wasser. Der Problemcharakter ist hierbei völlig unterschiedlich, er betrifft verschiedene Weltregionen mit divergierenden Ökonomien und verschiedenen Wirtschaftsweisen und Techniken. Ebenso divergieren die technischen Lösungsvorschläge. Im ersten Fall geht es direkt um eine effizientere Wassernutzung, im zweiten um eine nachhaltige Bodennutzung.

Das Ziel der gemeinsamen Betrachtung besteht zum einen darin, den Zusammenhang zwischen Wasser- und Bodennutzung exemplarisch zu verdeutlichen, zum anderen soll gezeigt werden, dass trotz der unterschiedlichen Problemlagen ähnliche Faktoren eine Institutionalisierung der Konzepte behindern.

Problemlage 1: Wasserknappe, urbanisierte Länder mit Bewässerungswirtschaft und niedrigen

bis mittleren Einkommen

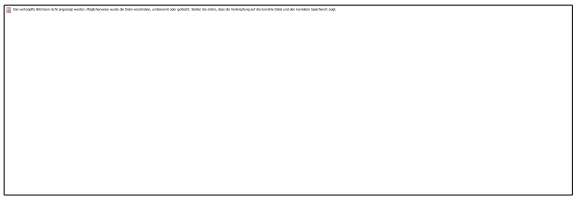
Angesprochen sind insbesondere Länder des Nahen Ostens und Nordafrikas. Beispielhaft wird hier näher auf Jordanien eingegangen.toptop Wasserknappheit, eine stark zunehmende Verstädterung und ein rasant steigender Wasserbedarf sind hier die hervorstechenden Charakteristika. Trotz der rückläufigen volkswirtschaftlichen Bedeutung des Agrarsektors werden in Jordanien noch knapp 70 Prozent der Wasserressourcen der Bewässerungslandwirtschaft zugeteilt. Die industrielle Entwicklung ist in den meisten der angesprochenen Länder nicht so dynamisch, wie noch vor rund zehn Jahren angenommen werden konnte. Der Bevölkerungszuwachs ist dagegen weiterhin hoch, und der Industriesektor kann den steigenden Bedarf an Arbeitsplätzen bei weitem nicht abdecken. Somit geraten gerade in Jordanien immer mehr Menschen auch in den Städten unter die ökonomische Armutslinie.toptop

Während im Falle Jordaniens die Land- bzw. Weidewirtschaft im Hochland unter marginalen Bedingungen erfolgt, befindet sich das Jordantal in einer landwirtschaftlichen Gunstlage, dort kann prinzipiell rentable und intensive Bewässerungslandwirtschaft betrieben werden. Es ist bekannt, dass alleine mit der Umstellung von Oberflächen- auf Tropfbewässerung rund 50 Prozent des Wasserbedarfs eingespart werden kann, und bereits 60 Prozent der Agrarflächen im Jordantal sind mit dieser Technologie ausgestattet. Unter den harten Konkurrenzbedingungen und unter dem durch die Wasserknappheit verursachten hohen Produktionsrisiko verfügen aber gerade die kleineren Betriebe nicht über das notwendige Investitionskapital, das solche und weitere Modernisierungsmaßnahmen erfordert. Aber auch durch Managementverbesserungen, wie z. B. wassersparende Anbausysteme, Nacht- oder Unterfolienbewässerung, Optimierung der Bewässerungsmengen u. a., könnten noch große Wassereinsparungen erreicht werden. Hier liegen die begrenzenden Faktoren für die Umsetzung in mangelnden Anreizen, mangelnder landwirtschaftlicher Beratung und dem fehlenden Vertrauen zwischen beratenden Institutionen und den Landwirten.toptop

Die Wasserpreise in Jordanien sind bis heute niedrig, jedoch ist die Wasserverfügbarkeit extrem unsicher, d. h., die Landwirte müssen mit großen Schwankungen bei der Wasserzuteilung zurechtkommen. Prinzipiell können landwirtschaftliche Kredite von der zuständigen staatlichen Bewässerungsinstitution, der *Jordan Valley Authority* (JVA), vergeben werden, jedoch kann diese mangels Flexibilität und praktisch ausgebildeten Personals auf die Bedürfnisse der Landwirte zumeist nicht eingehen, d. h., die Zusammenarbeit funktioniert nicht.

Große Einsparungen bzw. Effizienzsteigerungen wären in Jordanien und anderen urbanisierten Ländern außerdem durch eine systematische Mehrfachnutzung von Wasser möglich. Haushaltsabwässer könnten nach der Klärung zu Bewässerungszwecken verwendet werden, bevor sie in die Umwelt entlassen werden. Eine Mehrfachnutzung des Wassers erhöht die Wertschöpfung pro Mengeneinheit automatisch um einen sehr bedeutenden Faktor, auch wenn nur ein gewisser Anteil des Abwassers zur Wiederverwendung zur Verfügung steht, da ein Teil verbraucht wird bzw. im System verloren geht.toptop Das Konzept der Mehrfachnutzung existiert seit vielen Jahren und wird *de facto* besonders in Israel und Tunesien, aber auch in Jordanien von einer beträchtlichen Anzahl von Landwirten praktiziert. Warum kommt es aber nicht zu einem Durchbruch dieser Technologie, d. h. zu einer politisch-strategischen Umorientierung der Bewässerungslandwirtschaft in diese Richtung?

Umsetzungsvoraussetzungen und -hemmnisse einer systematischen Wiederverwendung von Abwasser



Die Umstellung auf eine systematische Mehrfachnutzung von Wasser verlangt institutionelle Reformen und sektorübergreifende Regulierungsmechanismen, welche die Siedlungswasserwirtschaft, Bewässerungslandwirtschaft und den Umweltsektor gleichzeitig berühren.

Primäre und sekundäre Bewässerungssysteme werden in den meisten Ländern von staatlichen Institutionen, aber zunehmend auch von Zusammenschlüssen verschiedener Wassernutzergemeinschaften bewirtschaftet. Insbesondere die Investitionen müssen vom Staat oder gemeinschaftlich unternommen werden, einzelbetrieblich sind sie keinesfalls leistbar.toptop

Bei der Umstellung auf die Bewässerung mit geklärtem Abwasser müssten streckenweise getrennte Leitungssysteme errichtet werden, d. h., dies wäre mit beträchtlichen Investitionskosten verbunden. Um für Landwirte Anreize zur Verwendung des Abwassers zu setzen, müssten die Preise nach Qualitätskriterien gestaffelt werden. Voraussetzung hierfür wäre wiederum die Schaffung einer transparenten Datenlage, zentraler Steuerungsmöglichkeiten sowie einer funktionierenden Qualitätsüberwachung. Darüber hinaus müssten Berater, Landwirte und Fachpersonal entsprechend geschult werden, um die neue Technologie zu beherrschen.

Entscheidend für eine erfolgreiche Umstellung ist zunächst die Akzeptanz der Wiederverwendung bei Landwirten und Verbrauchern, und diese setzt die kontinuierliche hygienische und chemische Unbedenklichkeit der geklärten Abwässer voraus. Es darf weder zu größeren Ertragsdepressionen bei den landwirtschaftlichen Kulturen kommen noch zu Gesundheitsgefahren für Landwirte oder Konsumenten. Nicht zuletzt sollte das Abwasser frei von nicht abbaubaren und toxischen Substanzen sein, um die Umwelt nicht zu gefährden, und es darf nicht zu einer Akkumulation von Salzen in den Böden kommen.

Rein technisch ist es möglich, diese Vorgaben zu erfüllen, jedoch erfordert ihre Einhaltung neben beträchtlichen Investitionen politischen Reformwillen und die Schaffung eines ausgeklügelten Systems an Regulierungsmechanismen. Hierbei ist es von zentraler Bedeutung, wie die Vor- und Nachteile der Reform auf die einzelnen betroffenen Sektoren und Interessengruppen verteilt sind und welche Kompensationsmöglichkeiten bestehen, um Risiken für einzelne Sektoren abzufedern.toptop Die nachstehende *Übersicht* (S. 19) zeigt die zu erwartenden Vor- und Nachteile bei einer solchen Umstellung des Wassernutzungssystems.

Es wird deutlich, dass mit der systematischen Wiederverwendung von Abwasser viele sektorübergreifenden Risiken verknüpft sind, die jeweils den "nachgelagerten" Sektor negativ betreffen. Solange ein Landwirt individuell marginales Wasser verwendet, trägt er auch das hiermit verknüpfte Risiko, weiß aber sogleich, dass die Verantwortung für Konsumentenrisiken schwer nachweisbar sind. Bei einer institutionellen Verankerung können diese Risiken nicht mehr verallgemeinert werden, sondern sie fallen auf den jeweiligen Sektor zurück. Schon deshalb müssen sie so niedrig wie möglich gehalten werden. Zudem müssen sie mit Kompensationsmechanismen abgefedert werden, um überhaupt als solche akzeptiert

werden zu können. Qualität und Zuverlässigkeit der Abwasserklärung sind daher die Schlüsselfaktoren, die über die landwirtschaftliche Rentabilität, die Konsumentensicherheit und Umweltverträglichkeit der Mehrfachnutzung entscheiden.

Hieraus folgt, dass die Ansprüche an die Klärtechnik durch eine systematische Mehrfachnutzung komplexer werden und sich die Verantwortungsbereiche der einzelnen Sektoren für die Einhaltung von Qualitätsstandards bei einem solchen System verschieben und ausweiten. Die *Übersicht* zeigt darüber hinaus, dass für den Konsumenten die Abwägung zwischen Vor- und Nachteilen der Wiederverwendung von Abwasser u. a. davon abhängt, ob ihm der Zusammenhang zwischen dem verbesserten Zugang zu Trinkwasser und der Wiederverwendung von Abwasser in der Nahrungsmittelproduktion bewusst wird.

Ein weiterer wichtiger Punkt, der über die Realisierungschancen einer systematischen Wiederverwendung von gereinigten Abwässern entscheidet, ist, ob in allen Sektoren eine umfassende und transparente mengen- und qualitätsbezogene Datenlage hergestellt werden kann, die eine zuverlässige Bewertung, Steuerung und Überwachung erst ermöglicht. Nicht nur in Ländern des Nahen Ostens zeichnen sich Wasserinstitutionen jedoch dadurch aus, dass sie schwerfällige Apparate mit Personalüberhang sind. Charakteristisch ist auch die Bedeutung von informellen Beziehungsnetzen, die innerhalb der Institutionen eher negativ für den Informationsfluss entscheidend sind. Die Transparentmachung von Daten über Sektorgrenzen hinweg und für die Öffentlichkeit ist daher gerade in diesen Ländern ein schwieriges und zeitaufwendiges Vorhaben.

Schlussfolgernd kann zunächst gesagt werden, dass die Institutionalisierung des Konzepts für eine Wiederverwendung geklärter Abwässer zwar interessante Perspektiven eröffnet, dass sie aber mit zahlreichen Problemen verknüpft ist. Die größten Probleme bestehen in der Haftung für mögliche Schäden, die durch eine unzureichende Abwasserqualität für die Landwirte, Konsumenten und die Umwelt entstehen könnten, wenn die Klärtechnik nicht zuverlässig funktioniert.

Um die Zuverlässigkeit abschätzen zu können, dürften hierbei zunächst das Sammeln und Zusammentragen von Erfahrungen und darauf aufbauend die Bildung von Vertrauen bei den Entscheidungsträgern und Akteuren aus den unterschiedlichen Sektoren zuträglich sein. Die Klärtechnik muss sich darüber hinaus neuen Fragen stellen, denn die Wasserqualität der Klärabläufe sollte in ihrer Zusammensetzung, inklusive Nährstoffgehalte, den Ansprüchen der Landwirtschaft entgegenkommen. Entfallen diese Vorteile, wird es umso schwieriger, dem Landwirtschaftssektor das Vorhaben plausibel zu machen.

Die Umstellung auf die Wiederverwendung von Abwasser bedarf beträchtlicher sektorenübergreifender Reformen. Damit diese ausgewogenen Charakter erlangen, ist es von zentraler Bedeutung, alle beteiligten Sektoren und möglichst viele Untergruppen mit Partikularinteressen in den Planungsprozess einzubeziehen. Im Vorfeld sollte zudem eine breite Aufklärungskampagne für die Öffentlichkeit stehen.toptop

Insgesamt machen die Ausführungen deutlich, dass die Umstellung der Wasserversorgungssysteme von der Einfach- zur Mehrfachnutzung weit mehr ist als eine technische Frage. Im Mittelpunkt stehen *institutionelle Fragen*, wobei in manchen Ländern der Reformprozess erst damit beginnen müsste, die Wasserinstitutionen selbst handlungsfähiger zu machen.

Problemlage 2: Wasserknappheit in Agrarländern mit Regenfeldbau und niedrigen

Einkommen

Eine andere große Ländergruppe mit wachsender Wasserknappheit sind die Länder Subsahara-Afrikas, wobei insbesondere die wirtschaftlich sehr einkommensschwachen Länder in der Sahel- und Sudanzone betroffen sind, aber auch Länder des südlichen Afrikas. Die meisten dieser Länder sind agrarisch geprägt, und die Mehrheit der Bevölkerung lebt unter Armutsbedingungen auf dem Lande, wobei die Landwirtschaft zu über 90 Prozent auf Regenfeldbausystemen basiert, d. h. weitgehend ohne Bewässerungstechnik funktioniert.

Das vorrangige Problem der auf Agrar- und Weidewirtschaft basierenden Länder in der südlichen Sahelzone besteht darin, dass die landwirtschaftlichen Böden und Weideflächen einer zunehmenden Degradierung unterliegen. Gleichzeitig wächst die Bevölkerungsdichte in den meisten Ländern stark an. Der Degradationsprozess ist sowohl auf globale Prozesse (Klimaverschiebung, Veränderung der Niederschlagsmuster) als auch auf Bewirtschaftungsweisen zurückzuführen, die der wachsenden Bevölkerungsdichte nicht angepasst sind. Die Degradation des Bodens geht mit einer zunehmenden Bodenerosionen einher, so dass schließlich "sterile" Böden mit harter Bodenoberfläche entstehen. In harte Bodenoberflächen kann das Wasser nicht mehr infiltrieren, der Grundwasserspiegel sinkt ab, und es entstehen die typischen Erosionsrillen - Ertragsminderungen sind die Folge.

Für die Sahelländer stellt sich somit das Wasserproblem in einer ganz anderen Form als für Gesellschaften mit Bewässerungstechnik. Ziel von Maßnahmen ist es hier zunächst, das Bodenwasser wieder pflanzenverfügbar zu machen, indem die Infiltrationsrate von Wasser und die Wasserhaltekapazität erhöht wird. Auf diese Weise käme es auch zu einem Anstieg der Grundwasserspiegel, ein weiterer Engpass für Mensch und Tier, da der Zugang zu Trinkwasser über Brunnen, d. h. direkt aus dem Grundwasser, erfolgt.

Entgegen der häufig anzutreffenden Vorstellung in der öffentlichen Debatte, der Degradationsprozess sei unumkehrbar, ist die *Wiederherstellung der Ertragsfähigkeit* degradierter Böden rein technisch gesehen kein sehr großes Problem. Seit vielen Jahren ist die afrikanische Bevölkerung mit internationaler Unterstützung dabei, solche Böden wieder in Wert zu setzen. Mit Hilfe von kleinen Erosionsschutzwällen werden zunächst die baulichen Voraussetzungen dafür geschaffen, Niederschlagswasser zur Infiltration zu bringen. Mit biologischen Begleitmaßnahmen (Aufforstung, Bepflanzung der Steinwälle, organische Düngung) werden die Humusgehalte angehoben und die dauerhafte Wirksamkeit der Maßnahme gewährleistet. Wenn dies so problemlos möglich ist, warum ist eine flächendeckende nachhaltige Bewirtschaftung der Agrarflächen Afrikas dennoch bis heute nicht erreicht?

Um den Degradationsprozess flächendeckend zu stoppen bzw. umzukehren, müsste das beschriebene Erosionsschutzkonzept in breitem Maßstab umgesetzt werden. Folgende Faktoren behindern jedoch die Umsetzung von Bodenschutzmaßnahmen:toptop

1. Das Transportkostenproblem

Die flächendeckende Umsetzung bodenstabilisierender Maßnahmen erfordert zunächst die Grundmelioration in Form der baulichen Maßnahmen, d. h. die Errichtung von Steinwällen und Ravinen. Besonders in steinarmen Gegenden verursachen diese Maßnahmen hohe Transportkosten. Auf kleinbäuerlicher Ebene sind diese nicht finanzierbar, und per Kopflast- oder Ochsenkarrenverfahren sind sie auch nicht rentabel.toptop

2. Das Gemeinwesenproblem

Ein wirksamer Erosionsschutz verlangt eine überbetriebliche und überdörfliche Planung, in etwa vergleichbar mit der Planung weiträumiger Bewässerungs- und Drainagevorhaben.

Außerdem erfordert er auch eine Planung unter Einbeziehung verschiedener Bevölkerungsgruppen. So sind die Ackerbauern und Viehzüchter in unterschiedlichem Maße von Erosionsschutzmaßnahmen betroffen. Während die Ackerbauern auf Basis individueller Nutzungsrechte für Ackerflächen agieren, gelten für Viehzüchter gemeinschaft-

liche Nutzungsrechte, und dies fördert bekanntermaßen die Übernutzung der Flächen *(tragedy of the commons)*.toptop

3. Unklare Bodenrechtsregelungen und Konflikte zwischen Bevölkerungsgruppen

Die Einführung moderner Bodenrechtsregelungen im Sahel haben vielerorts zur Existenz zweier paralleler Rechtssysteme geführt. Die Bevölkerung hält vielerorts noch an den traditionellen Regeln fest und besitzt über das moderne Rechtssystem kaum Informationen. Die Existenz zweier gleichzeitig gültiger Regelsysteme bewirkt Unsicherheit und verhindert somit Investitionsabsichten in den Boden.

Durch die Expansion des Ackerbaus in den letzten Jahrzehnten wurde in vielen Regionen des Sahels die Viehwirtschaft immer stärker eingeschränkt. Moderne staatliche Rechtssysteme und auch die meisten international unterstützten Ressourcenmanagementprojekte stützen diese Tendenz, da sie sich primär auf den sesshaften Lebensstil beziehen. Erosionsschutzmaßnahmen kommen bisher tendenziell eher den Ackerbauern zugute. Wie Viehzüchter hiervon verstärkt profitieren könnten, ist bisher noch nicht ausreichend geklärt.

Die Auflistung zeigt, dass auch bei dieser Problemlage *Investitions- und Regulierungsprobleme* dominieren und die flächendeckende Umsetzung der Konzepte verhindert.

In den Ländern Subsahara-Afrikas weisen die Institutionen im Allgemeinen noch eine geringere Kapazität auf als in Ländern des Nahen Ostens oder Nordafrikas. Dies bedeutet, die Institutionen sind für die Bevölkerung kaum wahrnehmbar, sie haben kaum finanzielle Mittel und setzen diese wenigen Mittel auch nicht in erster Linie armutsorientiert ein. Während bei der zuerst geschilderten Problemlage insbesondere die unterschiedlichen Sektoren und deren institutionelle Zusammenarbeit angesprochen waren, werden hier vor allem Interessengegensätze zwischen Bevölkerungsgruppen identifiziert, die harmonisiert werden müssen, wenn ein flächendeckender Boden- und damit Wasserschutz umgesetzt werden soll.

Zur Durchführung von Bodenschutzmaßnahmen durch die Bevölkerung bedarf es einer Reihe günstiger Rahmenbedingungen:

1. Die Maßnahmen am Standort müssen deutliche und sofortige Ertragswirkungen aufweisen.

2. Die Opportunitätskosten der Arbeit müssen zum Zeitpunkt der Erosionsschutzmaßnahmen gering sein.

3. Die externe Finanzierung des monetären Kostenanteils, d. h. die Übernahme der Transportkosten, muss gegeben sein.

Sollten Gemeinde- und Weideflächen einbezogen werden, dann müssen weitere Voraussetzungen erfüllt sein:toptop

- klare und gerechte Bodenrechtsregelung und wirksame Kontroll- sowie Sanktionsmechanismen, die allen Nutzergruppen als gemeinsame Planungs- und Handlungsgrundlage dienen können;

- Dezentralisierung der Administration, damit die Bevölkerung zu staatlich autorisierten Stellen als Verhandlungspartner Zugang bekommt und Vertrauen gewinnen kann;

- Partizipation aller Betroffenen an der Planung (partizipative Landnutzungungsplanung, LNP) der Maßnahmen. Betrachtung von Ackerbau und Viehzucht als komplementäre Formen der Bodenbewirtschaftung;

- Partizipation möglichst vieler Betroffener am Nutzen, Einzelfallvereinbarungen mit den zuständigen Institutionen oder Projektträgern.

Im Sahel ist der institutionelle Dezentralisierungsprozess, der u. a. eine effektive Zusammenarbeit zwischen Bevölkerung und Institutionen auf allen Ebenen erleichtern soll bzw. erst möglich macht, bei weitem noch nicht abgeschlossen. Zusätzlich leiden die Institutionen noch stärker als in anderen Regionen unter einer chronischen Kapital- und Kapazitätsschwäche. Solange hier ein Vakuum herrscht, sind weiterhin internationale Geberbeiträge gefragt, die diese Unterstützung auch mittelfristig leisten. Zu begründen sind diese Beiträge auch damit, dass die Länder des Nordens für Preisverzerrungen und globale Klimaveränderungen die Hauptverantwortlichen sind und somit die Bodendegradierung mit verursacht haben. Ein anderes Argument sind die hohen Folgekosten, falls die Unterstützung nicht gewährt wird. Ein entvölkerter Sahel ohne aufnahmefähige Fluchtziele in den umliegenden Ländern kann nicht im globalen Interesse sein. Neben direkten Investitionshilfen für die Grundmelioration sollte parallel hierzu jedoch ein Programm zum *Capacity Building* der nationalen Institutionen und Nutzergruppen durchgeführt werden, um diese dabei zu unterstützen, die Steuerungs- und Finanzierungsaufgaben langfristig selbst zu übernehmen.

Food Control

Volume 14, Issue 5 , June 2003, Pages 283-299
Cite or link using doi
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Water in food production and processing: quantity and quality concerns

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Received 19 September 2001; revised 11 June 2002; accepted 16 July 2002. ; Available online 20 January 2003.

Abstract

Water of high quality is or will become a scarce commodity in many areas. Food production and processing require large amounts of water of varying quality. Water reuse during food production and processing occurs and will likely increase in the future. Wastewater has been used for food production for many years in some locations. Awareness of the close association between water and food-borne disease is growing and thus there is a need to develop rational water use management plans within the food industry that maximize health protection. The food processing industry has long used hazard analysis and critical control point (HACCP) programmes to make their products safer. There is a trend in water supply to implement similar programmes. This article will focus on water quality and quantity issues in food production and in the factory. For food production, it is important to understand how water demand, sources of pollution, water reuse and contamination of food through water affect food safety.

Article Outline

1. Aim
2. Introduction
3. Water in primary production
3.1. Water demand and use
3.2. Sources of water contamination
3.3. Public health consequences of contamination during primary production
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3.6. Prevention of contamination in primary production
4. Water in the factory—food processing
4.1. Water demand and use
4.2. Sources of water contamination
4.3. Public health consequences of contamination during food processing
4.4. Prevention of contamination in factory production
4.5. Water reuse and recycling in the factory
5. Conclusion
References

Further Reading

1. Aim

The aim of this paper is to discuss the principal issues related to water quality and quantity in food production. Primary production to transformation (factory processing) is covered. Retail and catering issues will not be discussed. The paper is not intended to be a comprehensive review of all information but will focus on recent developments and future perspectives.

2. Introduction

Improvements in health over the past century have been underpinned by positive advances in the management of vital resources such as water and food. Water supply and quality, and food security and safety are intertwined. Freshwater resources and especially high quality freshwater resources are becoming increasingly scarce, driven by factors including population growth, urbanisation and probably global climate change. The availability of freshwater resources adequate in both quantity and quality is vital to food security and production. It contributes in initial production (irrigation, livestock watering, aquaculture) and in processing (as an ingredient, transport medium and hygiene aid). Food companies must therefore address the future trends relating to this resource.

The food and water industries have a common objective, namely that of supplying quality goods or services to consumers. Implicit in this objective is that the product or service should be `safe'.

Water, like food, is a vehicle for the transmission of many agents of disease and continues to cause significant outbreaks of disease in developed and developing countries world-wide. It was identified as the source of, among others, the worst outbreak of *Escherichia coli* O157:H7 in Canada to date (Kondro, 2000). A *Cryptosporidium* outbreak in Milwaukee, Wisconsin, USA in 1993, affected approximately 400,000 consumers and caused 54 deaths (Kramer, Herwaldt, Calderon, & Juranek, 1996; Hoxie, Davis, Vergeront, Nashold, & Blair, 1997).

Water can also contaminate food. In 1970, a cholera epidemic in Jerusalem was traced back to the consumption of salad vegetables irrigated with raw wastewater (Shuval et al., 1986). Helminths, protozoa and viruses also may be spread from contaminated water to food. Contaminated irrigation water has been associated with hepatitis A outbreaks in lettuce (Rosenblum, Mirkin, Allen, Safford, & Hadler, 1990), tomatoes (Williams, Bell, Berry, & Shapiro, 1994), raspberries (Ramsay & Upton, 1989), and strawberries (CDC, 1997a); and cyclosporiasis outbreaks in raspberries (CDC, 1996), lettuce (CDC, 1997b), and basil (CDC, 1997c). Ascaris infections have frequently been associated with the consumption of vegetables irrigated with untreated or inadequately treated wastewater (Blumenthal, Mara, Peasey, Ruiz-Palacios, & Stott, 2000; Mara & Cairncross, 1989).

In the context of this paper, people can be exposed to infectious agents or toxic chemicals through

– the ingestion of contaminated water incorporated into foods;
– the ingestion of foods irrigated with or harvested from contaminated water; and
– the ingestion of foods that have come into contact with contaminated water during processing.

There are many competing demands for fresh water and their number is increasing. They include food production and processing; domestic supplies; industry; tourism and leisure; energy production; navigation; and the need to maintain ecosystem integrity. Different uses

may be polluting and/or make quantity/quality demands on resources (see Table 1).

Water uses	Consuming	Contaminating
Domestic use	Yes	Yes
Livestock watering	Yes	Yes
Irrigation	Yes	Yes
Aquaculture	Yes	Yes
Commercial fisheries	Yes	Yes
Forestry and logging	No[a]	Yes
Food processing	Yes	Yes
Textile industry	Yes	Yes
Pulp and paper industry	Yes	Yes
Mining	Yes	Yes
Water transportation	No	Yes
Hydroelectric power generation	No	No[b]
Nuclear power generation	Yes	Yes
Recreation	No	Yes

Table 1. Consumption and contamination of water by common water uses
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Source: Bartram and Ballance (1996).

The pressures on the world's water resources are growing. Water usage in North America increased by approximately 800% from 1900 to 1995, while global water use in 2000 was estimated to be nearly three times that in 1950 (Shiklomanov, 1998). As demand increases, pollution of water resources has further reduced the availability of water of quality appropriate for given purposes. Increased demand and reduced availability inevitably affect quality (Ford & Colwell, 1996). Reduced water availability is already leading to attempts by the food industry to optimise its use.

The disposal of waste products is a major consideration in the water cycle that contributes to reduced quality and to which the food production and processing industries contribute. Much of the world faces challenges as a consequence of industrialised food production, due to high-density production of animal proteins (on land and in water), and the associated problems of effluent disposal. Efficient food production generally requires use of artificial fertilisers and pesticides and increases soil erosion and runoff. All of these activities have an impact on water resources. These growing pressures create a vicious cycle: increasing exploitation of water resources leads to more water pollution that further reduces the availability of clean water etc. Sustainable alternatives including water treatment and reuse where practical will need to be implemented during food production and processing if access to adequate water resources is to continue and thereby gains in food quantity, quality and affordability are to be maintained.

3. Water in primary production

3.1. Water demand and use

Primary production of food requires copious amounts of water. More than two thirds of all freshwater abstraction world-wide (and up to 90% in some countries) goes towards food production. Already freshwater resources are depleted in many areas of the world. By 2025, it

is estimated that 35% of the world's population will live in countries affected by water stress or scarcity (Gardner-Outlaw & Engleman, 1997; Hinrichsen, Robey, & Upadhyay, 1998). Rain fed agriculture is already practised to a maximum extent in many areas, therefore, increases in food production will require increased irrigation. Approximately 40% of the World's food is currently grown on irrigated land (Gleick, 2000). Worldwide, the amount of irrigated land is expected to grow by 0.6% a year between 1996 and 2030. However, due to population growth the amount of irrigated land per capita is estimated to have reached its peak in 1978 and has declined since then by 5%, with declines of 17–28% predicted by 2020 (Postel, 1999).

Irrigation is often inefficient and thus there are significant opportunities to reduce water use in food production. Postel (2001) estimates that freshwater use for irrigation can be reduced by significant amounts by introducing new techniques such as drip irrigation, efficient sprinkler systems, by timing water application to match plant requirements, and by developing new water efficient crop varieties. Moreover, improving irrigation efficiency may also increase crop yields and reduces water pollution by limiting the amount of runoff and controlling the process of salinisation (Gleick, 2000; Postel, 2001). For example, when farmers in India switched from conventional irrigation techniques to drip irrigation they were able to increase the crop yield per unit of water applied from 46% for potatoes to as much as 243% for sweet potatoes (Gleick, 2000).

Water savings during primary production can also be achieved by growing more crops during the cool season when there is less evaporation (and in some regions more rainfall), by better management of fallow land, and by better crop management (Seckler, 1996). For example, a project in Malaysia showed that 25% less water was required to grow rice by using a `dry seeding' approach compared to the traditional method that required pre-transplant flooding of the rice paddies (Seckler, 1996).

Water use can also be made more efficient by adapting the water quality to the crop. Seckler (1996) cites an example where salty drainage water from one crop is used to irrigate cotton, which is salt-tolerant. The highly salty drainage water from the cotton is used to irrigate halophytes (extremely salt tolerant plants).

In the future, water resources are likely to be impacted not only by population growth but also by greater economic prosperity. For example, as societies grow wealthier, meat consumption typically increases (see Table 2 and Table 3). It is much less efficient to use water to raise crops that are then fed to animals than it is to produce crops for direct human consumption. For example producing a kilogram of beef takes 8 to 85 times more water (depending on soil and climate conditions and irrigation methods) than growing a kilogram of grain (Gleick, 2001). As societies become more affluent, they will likely use more water for food production further reducing the quality and quantity of this resource (Table 2 and Table 3).

Region	Calories (Kcal) regional diets (1989)	Percentage of calories from meat	Estimated water[a] to produce regional diet (m^3/p/yr)
Africa, Sub-Saharan	2191	10	640
Centrally Planned Asia	2541	15	920
Eastern Europe	3345	28	1430
Former USSR	3253	30	1570
Latin America	2555	19	1030
Middle East/North Africa	2819	13	1070
OECD-Pacific/Oceania	2691	24	1210
South and East Asia	2485	12	770
Western Europe	3350	36	1710
North America	3133	35	1830

Table 2. Calories available by region, percentage of diet as meat, water needed to produce the average regional diet

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1&_image=tbl2&_ba=2&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=2cc1750c7a0f5ff86e3c08fbecfbb3bc(<1K)

Source: Gleick, 2000.

Crop/Food	Water Requirement (kg of water per kg of food produced)
Potato	500–1500
Wheat	900–2000
Alfalfa	900–2000
Corn/maize	1000–1800
Sorghum	1100–1800
Soybeans	1100–2000
Rice	1900–5000
Chicken	3500–5700
Beef	15000–70000

Table 3. Approximatea crop water requirements to produce food harvested

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Source: Gleick, 2000.

Aquaculture is a very diverse activity that takes place in a wide variety of freshwater, brackish water and salt water environments. Water quantity and quality requirements are highly variable and relate to the use of both in situ resources (e.g., water bodies) and abstracted water (e.g., ground water, surface water). The quantity of the water depends on the type and density of organisms being raised (Barg & Phillips, 1997). In recent years aquaculture has been one of the fastest growing sections of primary production (Rana, 1997). In 1995, aquaculture products accounted for nearly 26% of the world's fish harvested for direct human consumption and 6.2% of the worlds total farmed animal protein production. In Asia, fish supplies 24.5% of all animal protein to the diet—a large portion of which is produced in aquaculture (Tacon, 1997).

One way in which countries compensate for water scarcity is to import highly water demanding products such as grain. It takes approximately 1000 tons of water to grow 1 ton of grain. Therefore importing a ton of grain frees 1000 tons of water that can be put to other uses (e.g., industrial and commercial) (Postel, 1999). This strategy for water replacement works well as long as there is a global surplus of grain and countries that need to import it have enough money to pay for it. However, many of the current and future water scarce countries are poor and may not be able to afford to import enough food (Postel, 1999).

3.2. Sources of water contamination

Surface waters, particularly rivers, are difficult to protect from contamination. A range of anthropogenic activities may contaminate surface waters including; agriculture; municipal and industrial wastewater discharges; overloaded or leaking sanitation systems; improper disposal of garbage and hazardous wastes; mining; deforestation/landscape alteration; incineration of

wastes leading to airborne deposition of heavy metals (e.g., mercury, cadmium); industrial processes; combustion related air pollution which leads to acid rain and others (WHO, 1996a).
Agricultural activities are responsible for much water contamination. Concern about the impact of agriculture on the quality of water resources is often related to diffuse sources—contamination by agro-chemicals, nutrients and hazardous microbes (pathogens) in particular (EEA/WHO, 1997).
Intensive livestock operations concentrate animal wastes—often in on-site storage facilities such as lagoons that can contaminate surface and ground water sources with pathogens and/or nitrates. For example, in 1995, 25 million gallons of untreated effluent spilled from a hog waste storage lagoon into the Neuse River in North Carolina, USA. A similar event happened in the same river after flooding caused by hurricane Floyd in 1999 (Wright, 2001).
Livestock often act as non-symptomatic carriers of human pathogens (e.g., *E. Coli* O157, *Salmonella* spp., *Campylobacter*, *Cryptosporidium*) and their wastes may contain high concentrations of these organisms. Animal waste can therefore contaminate human and animal drinking water sources. Contaminated water used for livestock watering can result in the infection of many animals within the same herd or in different herds or flocks that use the same water source.
Pathogen transmission to other livestock has been associated with the use of inadequately treated manure and manure slurries. There are two reports of *E. coli* infection in cattle involving grazing after recent applications of farm slurry: one in which the cattle invaded a recently treated field; and, the second, a large study showing association between infection of cattle and grazing with a median delay of 10 days after application of waste (Goodburn, 1999).
Studies by Doyle (1998) confirmed that *E. coli* O157:H7 is a highly resistant pathogen capable of survival in water for long periods especially at low temperature. *E. coli* O157:H7 has been reported by Wang, Zhao, and Doyle (1996) to remain viable in bovine faeces for 70 days and Kudva, Hatfield, and Hovde (1995) demonstrated survival for 21 months in sheep manure. Other pathogens are also capable of long-term survival or even replication in the environment—particularly when they are protected in animal faeces. Robertson, Campbell, and Smith (1992) demonstrated that up to 40% of certain strains of *Cryptosporidium* oocyst remained infective after 176 days in cow faeces. The longer pathogens can survive in the environment, the more likely they are to contaminate water and potentially food crops.
In many areas, a significant problem affecting groundwater is nitrate contamination. Nitrates are applied to land as fertilisers, in manure and sludge, in wastewater, or enter the groundwater directly from leaking sanitation systems or animal waste storage facilities. Nitrates are very soluble and can contaminate aquifers through leaching. Nitrates are stable in ground water and can build up to high concentrations. A number of countries including China, Indonesia, Mexico, Moldova, Nigeria, Romania, Slovenia, the United Kingdom and the United States of America have reported high concentrations of nitrates in their groundwater. (Sampat, 2000; Nixon et al., 2000).
Pesticides can leach into ground and surface waters and may cause health effects in extremely low concentrations. Pesticides may be directly sprayed over crops grown in flooded fields (e.g., rice paddies) and have been found in significant concentrations in ground water from many countries (Nixon et al., 2000; Sampat, 2000). For example, Atrazine a herbicide is frequently identified in groundwater in the United States of America. Concentrations above the WHO guideline of 2 g/l have been identified in groundwater from a number of States in the USA (USEPA, 2000).
Aquaculture activities may also contaminate water. For example, fish feed and waste products from net-pens where fish are raised may add biological oxygen demand (BOD) and nutrients to the local environment, exacerbating eutrophication and the formation of anoxic conditions. Chemicals used in aquaculture, including pesticides and antibiotics, may also contaminate the

water and have a low probability of contributing to the spread of antibiotic resistant pathogens (WHO, 1999). Aquaculture activities also affect water quality indirectly. For instance, when mangroves and wetlands are destroyed to create new production areas soil erosion increases and sediments are washed into the water. However, some aquaculture activities can have beneficial effects on water quality. For instance, incorporating aquaculture into a well-designed wastewater treatment system can help to prevent water quality deterioration, especially when the alternative is discharging raw or partially treated wastes into surface waters. Similarly, cultivating seaweed in coastal areas can help to reduce nutrients in the water (Barg & Phillips, 1997).

3.3. Public health consequences of contamination during primary production

Contamination of foods during primary production can play a role in the transmission of food-borne disease; for example recent outbreaks of *E. coli* O157:H7 have been traced back to the use of contaminated water used during irrigation or propagation (FDA, 1999). In the 1990s, outbreaks of human illness associated with the consumption of raw vegetables and fruits (or unpasteurised products from them) have increased in many developed countries.

One study has demonstrated that *E. coli* O157:H7 could be taken into lettuce plants and seedlings from contaminated irrigation water and manure slurries systemically through the roots, resulting in contamination of the edible plant portions (Solomon, Yaron, & Matthews, 2002). If more evidence for this type of pathogen uptake is discovered this would have important implications for the use of manure slurries (and to a lesser extent wastewater) for the production of vegetables that are consumed raw. *E. coli* O157:H7 is of particular concern because of its ability to survive in the environment (Wang et al., 1996), its low infectious dose (less than 1000 cells) (Ackers et al., 1998), and its potential for causing severe health outcomes in susceptible populations (e.g. children). However, more research is needed to find out how widespread this phenomenon is and its significance to public health.

Seed sprouts are particularly susceptible to contamination from manure or contaminated water. The warm moist conditions under which these are grown can facilitate the growth or re-growth of pathogens. The production and consumption of raw seed sprouts has increased in many countries. Consumption of these products has been associated with a number of disease outbreaks. For example, in Japan over 6000 people became ill when they ate radish sprouts contaminated with *E.coli* O157:H7 (Infectious Agents Surveillance Report, 1997). Other outbreaks associated with contaminated sprouts have occurred in Canada, Denmark, Finland, the United Kingdom, the United States of America, and Sweden (Taormina, Beuchat, & Slutsker, 1999).

The regulation of water quality for irrigation is of international importance because agricultural products grown with contaminated water may cause health effects at both the local and international levels. Exports of contaminated fresh produce from different geographical regions can facilitate the spread of both known pathogens and strains with new virulence characteristics into areas where the pathogens are not normally found or have been absent for many years (Beuchat, 1998). As food production and trade expands, international guidelines are increasingly important to prevent outbreaks of food borne disease and pathogens from being introduced into new geographical areas. For example, shigellosis outbreaks occurred in Norway, Sweden and the United Kingdom in 1994 due to contaminated lettuce imported from southern Europe (Frost, McEvoy, Bentley, Andersson, & Rowe, 1995; Kapperud et al., 1995). Furthermore, a cyclosporiasis outbreak in the United States was linked to the consumption of contaminated raspberries imported from Guatemala (CDC, 1996).

Contamination of seafood harvesting areas (particularly where shellfish are harvested) can have health impacts. In 1988, the consumption of contaminated shellfish in Shanghai China led to an outbreak of hepatitis A involving approximately 300,000 cases (Lees, 2000).

Norwalk viruses have also been implicated in disease outbreaks associated with the consumption of raw oysters (CDC, 2000a). In some countries (e.g., Japan) contaminated shellfish cause a significant percentage of the food-borne illnesses reported each year (Cato, 1998).

Excessive levels of nitrates are associated with methaemoglobinaemia in bottle-fed infants when contaminated ground water is the source of drinking water (WHO, 1996a). Methaemoglobinaemia in infants has been reported in a number of countries—particularly in Eastern Europe (Knobeloch, Salna, Hogan, Postle, & Anderson, 2000).

In many countries, industrial wastewater is often mixed with municipal wastewater and is used for irrigation. Industrial wastes may contain toxic organic and inorganic chemicals that can be taken up by crops. For example, in Japan, China including the province of Taiwan, rice accumulated high concentrations of cadmium (and other heavy metals) when it was grown in soils contaminated with irrigation water containing high levels of industrial discharges (Chen, 1992). In Japan, Itai–itai disease—a bone and kidney disorder—associated with chronic cadmium poisoning, occurred in areas where rice paddies were irrigated with water from the contaminated Jinzu river (WHO, 1992). In some parts of China, the use of industrial wastewater for irrigation is thought to be associated with health effects. For example, in affected areas a 36% increase in hepatomegaly (enlarged liver), and a 100% increase in both cancer and congenital malformation rates were observed compared to control areas where industrial wastewater was not used for irrigation (Yuan, 1993).

For occupational safety pesticide exposure and infection by water-borne helminths following the use of wastewater and excreta in agricultural irrigation are concerns. Epidemiological studies have shown that crop irrigation with untreated or inadequately treated wastewater causes a significant increase in intestinal nematode infections in crop consumers and field-workers (Blumenthal et al., 2000; EEA/WHO, 1997).

The health risks associated with chemicals found in wastewater and sludge may need to be given more attention, particularly as the level of industrialization increases in developing countries. To control adverse health and environmental effects from toxic substances, industrial wastes should be adequately pre-treated to remove these chemicals and/or should be managed separately from municipal wastewater and excreta.

3.4. Use of wastewater in primary production

As populations increase, more human excreta are produced. Most methods of disposing of excreta damage health and the environment including sewerage. Sustainable alternatives must be found that protects human health and the environment. Fortunately, wastewater is particularly suited for use in agriculture because of its nutrient and water content. In water-scarce areas wastewater, both treated and untreated, is often used to irrigate crops. This has important health implications, which may be both beneficial and detrimental, at the local level and the international level. However, evidence suggests that wastewater can be used safely in agriculture and aquaculture, if adequate safeguards are incorporated into the process. WHO Guidelines for wastewater and excreta use in agriculture and aquaculture provide a framework for wastewater quality for use in crop production. The WHO Guidelines for the safe use of wastewater and excreta recommend a multi-barrier approach to maximize health protection. These Guidelines are currently under revision.

In a limited water quality survey of rivers in Central and South America, Europe and Asia and the Pacific, many of the rivers exceeded WHO faecal coliform guideline targets for unrestricted irrigation using wastewater (WHO, 1987; Mara & Cairncross, 1989). For example, 18 out of 31 (58%) rivers sampled in Europe did not meet the faecal coliform guideline value (WHO, 1987; Mara & Cairncross, 1989). Thus, in some cases, imposition of strict water quality standards will restrict the use of treated wastewater in agriculture and could paradoxically lead to the use of less safe water. Similarly, water quality guidelines need

to be adapted for the social, economic, and environmental conditions of each country. When countries with inadequate resources for wastewater treatment adopt overly strict water quality standards for use in agriculture the end result is that they may be ignored entirely. WHO guidelines for wastewater use in agriculture are protective of public health but still allow for the cost-effective recovery of the valuable nutrient and water resources in the wastewater.

3.5. Use of sludge in primary production

Sewage sludge is defined as residual sludge from sewage treatment plants that treat domestic or urban waste-waters, and from other sewage plants treating waste-waters or a composition similar to domestic and urban waste-waters (CIWEM, 1995). Sewage sludge unless it is adequately treated, contains large numbers of pathogenic micro-organisms.
Sewage sludge is often applied to agricultural lands because of its value as a soil conditioner and fertiliser. Raw sewage contains a wide range of pathogens, many of which are also food-borne (Table 4). Primary and secondary wastewater treatments do not adequately remove pathogens without further steps. Tertiary treatment of wastewater reduces the concentrations of most microbes-sometimes to non-detectable levels, but adds significantly to the cost and complexity of the process (Table 5). However, such treatments are currently not widely used in many areas (EEA/WHO, 1997). Pathogens that are removed from the wastewater by treatment usually end up concentrated in the sludge.

Table 4. Examples of pathogens associated with raw domestic sewage and sewage solids (NRC, 1996)
/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6T6S-47RB2MV-1&_image=tbl4&_ba=4&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=904152305463233ef312fa40e023019f(<1K)

Table 5. Typical numbers of micro-organisms found in various stages of wastewater and sludge treatment (NRC, 1996)
/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6T6S-47RB2MV-1&_image=tbl5&_ba=5&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=709a302d78d7156982447c5b67f27fc8(5K)

Many questions have arisen regarding the public health and environmental implications of the land application of wastewater and sludge. The application of sludge through spraying and other means leads to concern about how potential contaminants may affect water sources. The use of untreated wastewater sludge and manure or partially treated manure slurries as fertilisers for the production of fruits and vegetables is a major contributing factor to contamination that causes foodborne disease (Beuchat, 1998; MacGowan, Bowker, McLauchlin, Bennett, & Reeves, 1994). In Switzerland salmonellosis in humans attributable to the use of sludge has led to a decision to require all sludge to be pasteurised (WRC, 1998). Many of the statutory controls on the treatment and use of sewage sludge in agriculture were established before *E. coli* O157 or *Cryptosporidium parvum* had been widely recognised as important pathogens.

Sludge and some artificial fertilisers may contain heavy metals that could potentially pollute the soil and groundwater. Many heavy metals are insoluble and are adsorbed by soil particles but several heavy metals, such as cadmium, are soluble and may pollute the groundwater. Heavy metals tend to accumulate in soils over time, increasing the chances that they will be taken up by plants. For example, Grössman (1988) cited in WHO (1991) found elevated levels of nickel in green vegetables, cabbage, onions, beans and peas grown on soils contaminated with nickel from sewage sludge application.
Wide variation has been found among national rules regarding the required treatment of sewage sludge (WRC, 1994) (Table 6). The 1986 EU Directive (86/278/EEC) provides general requirements for sludge used in agriculture. The EU Working Document on Sludge (3rd Draft, 27 April 2000) specifies required treatments and restricts the circumstances where sludge can be applied to land. Sludge treatments are required to achieve specific removals of indicator bacteria (e.g., *E. coli* and *Salmonella* spp.) and concentration limits for heavy metals and some organic compounds are specified. In the United States of America, the Part 503 Sludge Rule (Table 7) is the current management strategy for the application of sludge to land. These standards use risk assessment information to maximize health protection. However, Isole, Kyvsgaard, Nansen, and Henriksen (1991) suggested that the prescribed waiting period between the application of Class B sludge and animal grazing may not be adequate to prevent the transmission of tapeworm to grazing cattle. Barbier, Perrine, Duhamel, Doublet, and Georges (1990) also concluded that sewage sludge containing *Taenia saginata* eggs offers a serious risk for cattle even after a three week non-grazing period. Al-Ghazali and Al-Azawi (1986) reported that treatment of sewage does not always yield a cake

or final discharge free of *Listeria*.

Table 6. Examples of legislated treatment of sewage sludge for agricultural use in Europe and the USA (WRC, 1994)
/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6T6S-47RB2MV-1&_image=tbl6&_ba=6&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=70e9b06b4d3c306021a8d40b1ba1a584(19K)

(Every EU country has different regulations.)

Table 7. EU and USA pathogen limits for sewage sludge (WRC, 1994)
/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6T6S-47RB2MV-1&_image=tbl7&_ba=7&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=24718c01a53be2c5b7c4b0eb52f19dde(9K)

Class A is the applied to land with which the public is expected to be in contact.

Class B is the land with which the public is not expected to be in contact.

The practice of using treated effluents and sludge on land used for food crop production is likely to be limited by several factors:

1. Public health concerns regarding pathogens and toxic chemicals.
2. Concerns about heavy metals and organic chemicals building up in soils. Legislation in many countries is making it more difficult to use treated sludge because of this. For example, a recent statement from the European Community Economic and Social Committee on the use of sewage sludge in agriculture indicated that heavy metal levels in sludges should be set at such a level that over a period of 10,000 years the concentrations of heavy metals in the receiving soils should only be allowed to increase by a total of 100% (Frerichs, 2000). If this policy is implemented it would severely restrict the current use of sewage sludge in agriculture.
3. Availability of cropland close to wastewater treatment plants (not usually relevant for sludge).
4. The costs associated with the use of treated effluents and sludge that stem from the perception that negative health effects could result. Food producers and retailers are concerned about the potential liability for health risks attributed to the consumption of food grown with the use of treated wastewater effluents or treated sludge. There is a need for convincing scientific evidence that all aspects of the process are being carefully managed.

3.6. Prevention of contamination in primary production

In general, contamination of water and food during primary production can be reduced by
Treating wastewater and sludge adequately before it is discharged into surface water bodies or applied to land.
Diverting industrial wastes from municipal wastewater streams or pre-treating industrial waste to remove toxic chemicals.
Restricting application of animal manure's to soil.
Constructing and using well operated and maintained sanitation facilities that inactivates pathogens or prevents their release into the environment. Latrines should be placed a safe distance (e.g. at least 30 m) from water wells and away from shallow aquifers and porous soils.
Selecting appropriate crops.
Protecting springs and wells from surface drainage and flooding. Animal husbandry should be adequately controlled or excluded in zones near springs and wells.
Optimising the use of chemical fertilisers and pesticides to match crop requirements and crop pest lifecycles.
Preventing direct overspray of pesticides over water bodies. Respect a minimum distance between spraying operations and water. Establishing unsprayed "buffer zones" alongside a watercourse will reduce the likelihood of contamination. In the Netherlands it is predicted that this method along with measures to reduce atmospheric deposition and leaching could reduce pollution in water by 70–80% (WHO, 1996a; EEA/WHO, 1997).
Developing microbial water quality standards for harvesting filter-feeding shellfish.
Monitoring of water quality and shellfish-flesh.
Numerous pathogens are capable of survival in water and the environment for long periods especially at low temperature. Treatment of contaminated water or product with disinfecting chemicals such as chlorine or chlorinated water reduces populations of pathogenic bacteria but cannot eliminate them. Other pathogens such as viruses, protozoa or helminths are generally more resistant to chlorine than bacteria by varying degrees. Reduction in risk can better be achieved through controlling points of contamination including in the field (Beuchat & Ryu, 1997). Multiple barrier approaches have been included in WHO guidelines since the mid 1980s (Bartram, Stenstrom, & Fewtrell, 2001; Mara & Cairncross, 1989).

When industrial wastewater is mixed with municipal wastewater high concentrations of toxic chemicals may be found in the sludge turning it into a hazardous waste that requires special disposal to limit adverse health and environmental effects. Additionally, toxic chemicals can interfere with the biological processes that are used to treat the wastes thus reducing the effectiveness of the treatment. Therefore, it is important to separate toxic industrial wastes from municipal wastes before treatment to preserve sludge reuse options and protect public health.

WHO guidelines for the safe use of wastewater and excreta in agriculture and aquaculture establish microbial quality targets but they also emphasise best practices compatible with HACCP principles. When implemented these reduce the potential health effects associated with the use of wastewater and excreta (including sludge) in agriculture (Mara & Cairncross, 1989). Because helminth infections often pose the greatest health risks to farm workers (and their families) and crop consumers from the use of wastewater, sludge or excreta in agriculture (Mara & Cairncross, 1989; Blumenthal et al., 2000), WHO Guidelines focus on treatments that significantly reduce the viability of helminth eggs. Helminth eggs are generally very environmentally persistent. Excreta and sludge treatments therefore usually require storage for many months to ensure helminth egg inactivation. Storage times can be reduced when the excreta and sludge are allowed to digest at higher temperatures.

WHO recommends each of the following procedures for the treatment of sludge, excreta, and nightsoil to minimise adverse health effects prior to sludge disposal or use of sludge or excreta as a fertiliser (Mara & Cairncross, 1989, Helmer & Hespanhol, 1997; WHO, 1996b):

storage for 2 years at ambient temperatures (warm climates), or

batch thermophilic anaerobic digestion at 50–55 °C for 13 days, or

forced-aeration co-composting of excreta with domestic refuse for one month (temperature should rise to 55–60 °C), followed by 2–4 months of maturation, or

raw sludge and excreta can be safely applied to the land by subsurface injection, or placed in trenches and covered with at least 25 cm of soil before crops are grown (where soil conditions and the depth to the water table permit), or

liquid nightsoil can be stored for one week and applied to land but the settled sludge that may contain high concentrations of helminth eggs should be stored for at least a year or digested as above.

Seed sprouts—a unique case

Sprouts are grown from seeds in warm and humid conditions that facilitate the growth or re-growth of bacteria that may be present on the seed or in the water. Rinsing seeds in a chlorine solution prior to growth is not highly effective for reducing bacterial concentrations because the bacteria may be protected within the seed itself or may be introduced from the water or during handling. Moreover, even a small number of pathogenic bacteria may be able to grow to an infectious dose rapidly under the warm and moist conditions used to develop sprouts (Taormina et al., 1999). The CODEX Alimentarius Commission recommends that natural fertilisers such as manure and sludge should be highly treated to significantly reduce pathogens before they are applied to crops producing seeds for sprout production. Similarly, the Commission recommends that the quality of the water used should be dependent on the stage of the process. Potable water should be used to wash the seeds and during the sprouting process (CODEX Alimentarius Commission, 2000).

Where biological contamination of water and food products is likely (e.g., when inadequately treated wastewater is used as a water source) then industrial crops that will be processed with heat (e.g., potatoes, vegetables for canning etc.) can be grown (Mara & Cairncross, 1989).

Nitrate contamination of surface and ground-waters can be reduced by improving land management practices (e.g., by establishing buffer zones near streams) and by closely

matching fertiliser applications to crop nutrient requirements (GESAMP, 2001).
Contamination of water and food with pesticides can be reduced by adopting integrated pest management strategies and by maximising pesticide efficiency by targeting specific pests at appropriate times (i.e., in the right season, or to correspond with a particularly vulnerable life stage) (GESAMP, 2001).
Some shellfish (such as mussels, oysters, and clams) obtain their food by filtering large quantities of water and are therefore particularly susceptible to contamination. Excreta-related human pathogens and heavy metals are taken in with the food particles and can be concentrated in the tissues. Shellfish are also frequently eaten raw or partially cooked. Before marketing, shellfish and other fish may be held in clean water to reduce excreted organisms—a process known as depuration. However, depuration is highly variable and often ineffective at removing contaminants—particularly viruses (Edwards, 1992; Power & Collins, 1990).
Methods for preventing contamination of filter-feeding shellfish often focus on monitoring microbial indicators in harvesting areas and restricting harvesting in pollution prone locations (e.g., near sewage out-falls) (USFDA, 2000). However, this approach has limitations. Current microbial indicators may not correspond to virus concentrations in the water (WHO, 1996a) and thus filter-feeding shellfish can still become contaminated even when they are growing in areas that meet water quality standards (Griffin et al., 1999).

4. Water in the factory—food processing

4.1. Water demand and use

Water use during transformation is significantly lower than during primary production but it is none the less still important. Water is a significant component of many foods. It can either be added directly as an ingredient or be present as part of the raw materials (see Table 8). Food producers have been legitimately adding water to food since food processing began. There are also many examples of water as a processing aid including use as a thermal transfer medium,

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as a transport medium and in cleaning.

Process	Relative water quantity	Water quality
Primary production		
Aquaculture	High	Low–Medium
Irrigation	High	Low
Special cases (e.g., sprouts)	High	High–±Potable
Food processing		
Direct preparation of product	Low	High–Potable
Bottled water	High	High–±Potable
Cooling water	High	Medium–High
Product washing	Medium–High	Medium–High
Fluming water	High	Medium–High
Production of ice, hot water, and steam	?	Medium–High
Air conditioning and humidity control	?	Medium–High
Starting-up, rinsing and cleaning of processing equipment	High	High
Cleaning and disinfection of processing facilities	High	Medium
Sanitization water	?	?
Boiler feed water and fire extinguishing	High	Medium

Table 8. Water quantity and quality requirements for selected processes in food production
/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6T6S-47RB2MV-1&_image=tbl8&_ba=8&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=79a8e27eb9e13e74e78dec6bc9207a4b(36K)

Sources: CODEX Alimentarius Commission, 2000.

Currently food companies are putting much effort into reducing water consumption during transformation and significant savings can be made. There are five ways of reducing water consumption in food processing premises:
Reduction in uncontrolled use.
Improved planning and control.
Water reuse.
Water recycling after treatment.
Layout design improvements.
Typically water consumption can be reduced by up to 30% by simple cultural and operational changes with little capital investment. Examples include awareness and monitoring programmes and taps that automatically shut-off when not in-use. Similar savings are also possible with reuse, recycling and design improvement programmes however capital investment is higher and greater consideration needs to be given to the impact of the changes on finished products quality and safety.

4.2. Sources of water contamination

The principle ways in which water can impact on contamination of the food products in the factory are:

The incoming water itself.
The factory environment including the water storage and distribution system.
Factory workers.
In practice the absolute exclusion of all pathogens from domestic water supply is an unachievable goal. Water should present a negligible risk to public health (be "safe") which does not imply sterility, nor the complete absence of pathogens. If water is "safe" or potable then any viruses or pathogenic protozoa that may be introduced into foodstuffs should not represent a significant health risk. The same cannot necessarily be said of bacteria subsequently introduced to foodstuffs which under certain conditions may be subject to re-growth.
Our understanding of the behaviour of micro-organisms in the environment is slowly developing. For example Brown and Barker (1999) reported that "In situ in the natural environments micro-organisms exist in a nutrient deprived, slow or non-growing state in suspension (planktonic) or, predominantly as biomasses and adherent biofilms (for a review of biofilms and their relevance to the food industry, see Kumar & Anand, 1998; Hood & Zottola, 1995). Protozoa can act as an important reservoir [of pathogenic bacteria] in the environment. Moreover, organisms such as *Legionella pneumophila* and *Mycobacterium avium* grown in amoebae have been shown to have increased virulence as compared to cells grown on agar."
Personal health and hygiene play a critical role in the controls for controlling microbial contamination. Faecal-oral diseases are a primary concern. Workers during the growing, harvesting, sorting, processing and packaging of foods can spread these diseases. Infected workers have been implicated as the source of several food-borne outbreaks (EEA/WHO, 1997).

4.3. Public health consequences of contamination during food processing

Contamination of food products during transformation can play a role in the transmission of food-borne disease; for example cross contamination of meat products during processing can lead to human disease outbreaks (Armstrong, Hollingsworth, & Morris, 1996; Tuttle & Gomez, 1993). Water can play an important role in this process.
A recent outbreak of cryptosporidiosis in the USA highlighted the potential impact of water supply quality on food producers. During the USA outbreak food manufacturers who could have used the affected water where forced to recall potentially affected product even though no cases of cryptosporidiosis where traced back to the consumption of contaminated food. This is potentially of great significance for the food industry. Water quality monitoring—particularly for microbial contaminants—does not and realistically as yet cannot take place in real time. Awareness of the incidence of water and food born illness may only come about after the gathering of substantial epidemiological evidence. It is therefore possible that contaminated non-potable water may have been supplied to food companies for some time before they are made aware of it. The lag-time between water quality monitoring and a discovery of contamination means that responses may occur some time (up to 3 months) after the event has occurred. Thus, products produced before and after the issuing of a "boil water notice" may be affected.
Cryptosporidium is resistant to treatment with chlorine, and monitoring is not continuous, consequently, occasionally a slug of contamination can pass through the treatment works even in water considered to be potable (Gale & Stanfield, 2000). Additionally, *Cryptosporidium* has been identified on fresh produce (Monge & Chinchilla, 1996) and caused a disease outbreak associated with unpasteurised apple juice (Millard et al., 1994). Because the parasite is chlorine resistant, contamination could be spread to other produce via chlorinated wash water. However, in 2000 a food research association (CCFDRA) published an analysis of the risk posed to the food industry by *Cryptosporidium* contamination of the water supply. The

report concluded that for the majority of commercially processed foods *Cryptosporidium* represented either a low or negligible risk (Water quality for the food industry: management & microbiological issues, 2000). To date no incidents of cryptosporidiosis have been attributed to commercially processed foods (Cryptosporidium, 2001).
This issue raises the concept of suitability for intended use and "fit for purpose" at point of consumption. Some possible examples of suitability for use are given in Table 8.

4.4. Prevention of contamination in factory production

Food processors may source water either from municipal suppliers or from their own wells. The type and degree of treatment required to make water safe differs depending on the quality of the raw water source. It is important to define water quality targets and determine the tolerance of variation from these targets. Procedures need to be in place to effectively address failures to meet water quality targets. As with other things in life, prevention is better than cure and prevention of pollution rather than technological intervention to remove it is always preferable.
The fundamental purpose of water treatment is to protect the consumer from pathogens and from impurities in the water that may be injurious to human health or aesthetically unpleasant. Where appropriate, treatment should also remove impurities which, although not harmful to human health, may make the water unappealing, damage pipes, plant or other items with which the water may come into contact, or render operation more difficult or costly (WHO, 1996a). These purposes are achieved, by introducing successive barriers, such as coagulation, sedimentation, filtration and advanced treatments, to remove pathogens and impurities. The final barrier is often disinfection (WHO, 1996a). Table 9 provides an overview of water treatment technologies and their applications.

Table 9. Overview of representative unit processes and operations used in water reclamation
/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6T6S-47RB2MV-1&_image=tbl9&_ba=9&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=a37e544cf3ea570e5856a80bcf148b5d(15K)

Source: Adapted from Asano and Levine, 1998.

WHO Guidelines for drinking-water quality set microbial and chemical standards for potable water. The new third edition of the drinking water guidelines expand the use of risk assessment and further incorporate the use of HACCP principles, and are intended for applications where "potable" quality is called for.
HACCP, the system, is a systematic approach to identification, assessment and control of hazards (CODEX Alimentarius Commission, 1997) during production, processing, manufacturing, preparation and use of food, water, or other substances to ensure that the food, water or other substances are safe when consumed or used. The HACCP system incorporates safety control into the design of the whole process rather than relying solely on end-product testing. Therefore, the HACCP system provides a preventive and thus a cost-effective approach to product safety. Initially created for the food processing industry, HACCP has subsequently been applied to a number of different processes including drinking water treatment, aquaculture production, and the use of sewage sludge in the agriculture industry (Havelaar, 1994; Garrett, Lima dos Santos, & Jahncke, 1997; Godfree, 2000).

Access to a sufficient supply of safe water is essential in maintaining public health. In situations where there is inadequate water, direct and indirect effects on health are observed. Poor hygiene, enforced by the lack of water, results in the increased transmission of infectious disease (Black et al., 1981; EEA/WHO, 1997). A supply of potable water to factory workers is therefore important in minimising the risk of contamination of food products with infectious pathogens.

4.5. Water reuse and recycling in the factory

In the factory, there are possibilities for increasing water use efficiency and promoting water reuse. Water reuse can be made more efficient by targeting the water quality requirements to the particular process. However in many countries potable water use is a requirement for all applications in food premises. Matching water quality requirements with the type of water use requires an analysis of the critical control points and an evaluation of the potential for contamination of the food products. For example, using water of lower quality might be appropriate for washing the factory floor but could pose a health risk if it is used for washing equipment surfaces that come into contact with the food product. Therefore in addition to developing a framework for water reuse in food production/processing, where possible water reuse in the factory should be integrated into existing HACCP programs.
Water that is recycled will need to be treated to improve its quality particularly when it comes into contact with food or beverage products or is used to clean surfaces that will come in contact with the products (see Table 8). In 2000, the CODEX Alimentarius Commission published "*Proposed Draft Guidelines for the Hygienic Reuse of Processing Water in Food Plants*" (see text box) (CODEX, 2000b). Some companies that find themselves competing for increasingly scarce water supplies have found that it is more cost effective to treat and reuse their process water than to locate new supplies (Wouters, 2001). Advanced water treatment technologies (see text box) make it possible to treat water to a very high degree, significantly reducing potential health risks associated with water recycling. It is even possible to treat wastewater to such a high degree that it can be safely used as a supplement to potable drinking water supplies—as the city of Windhoek, Namibia has done since 1968 (Haarhoff & van der Merwe, 1995). However, treating water to such a degree is expensive. The quality of the water and thus the degree of treatment required, should correspond to the water use (see Table 8 and Table 10). Matching water quality requirements with the type of water use requires careful analysis. Therefore developing a framework based upon "fit for purpose" for water reuse in food production/processing would also benefit water recycling programmes.

CODEX Alimentarius Commission, *"Proposed Draft Guidelines for the Hygienic Reuse of Processing Water in Food Plants"*.
Among other requirements the CODEX guidelines specify the following:

Reuse water shall be safe for its intended use and shall not jeopardise the safety of the product through the introduction of chemical, microbiological or physical contaminants in amounts that represent a health risk to the consumer;

Reuse water should not adversely affect the quality (flavour, colour, texture) of the product;

Reuse water intended for incorporation into a food product shall at least meet the microbiological and, as deemed necessary, chemical specification for potable water. In certain cases physical specifications may be appropriate;

Reuse water shall be subjected to on-going monitoring and testing to ensure its safety and quality. The frequency of monitoring and testing are dictated by the source of the water or its prior condition and the

intended reuse of the water; more critical applications normally require greater levels of reconditioning than less critical uses;

The water treatment system(s) chosen should be such that it will provide the level of reconditioning appropriate for the intended water reuse;

Proper maintenance of water reconditioning systems is critical;

Treatment of water must be undertaken with knowledge of the types of contaminants the water may have acquired from its previous use; and

Container cooling water should be sanitised (e.g., chlorine) because there is always the possibility that leakage could contaminate the product.

Table 10. Examples of water reuse in food and beverage production
/science?_ob=MiamiCaptionURL&_method=retrieve&_udi=B6T6S-47RB2MV-1&_image=tbl10&_ba=10&_user=1457700&_coverDate=06%2F30%2F2003&_handle=W-WA-A-A-AU-MsSAYZW-UUW-AUCDWAUZDU-AWCZCEAVD-AU-U&_rdoc=1&_fmt=full&_orig=browse&_srch=%23toc%235038%232003%239998599994%23426530!&_cdi=5038&view=c&_acct=C000052715&_version=1&_urlVersion=0&_userid=1457700&md5=8dc1c4dd4b505d064119f2177dfb18fa(57K)

Source: CODEX Alimentarius Commission, 2000.

Because water and food-borne diseases are often closely linked it is important that water use and reuse in food production and processing be evaluated using the same HACCP approach.

5. Conclusion

To achieve sustainable water management both the primary producers and food processors need to recognise and engage in managing their roles as water consumers and polluters. A first step may be to use available water more efficiently. As discussed, there is large potential for increasing the efficiency of water use in primary production and in food processing. Reducing the amounts of water used may also correspond to a reduction in water pollution—particularly in primary production.

In recent year's food producers have recognised the unsuitability of the end product testing approach with regard to pathogens either in raw materials or finished goods. This is largely due to recognition of the severe limitations of among others the use of indicator organisms and sampling. General agreement exists amongst food processors that Quality Assurance systems based upon a preventative approach are more effective for assuring food safety than end product testing. HACCP is recommended as the QA tool to meet the current and future demands of the world's food supply (WHO, 1993).

There is a disparity between legislation requirements for food companies and companies supplying municipal water to the food industry. Water companies are currently in a unique position as suppliers of raw materials to the food-processing sector. EU legislation General Food Hygiene Directive EU 93/43/EEC requires that HACCP principles be applied to all food processing operations. All suppliers to food processors must therefore have HACCP Plans. The only exception is water utilities.

Application of HACCP systems in many different manufacturing or treatment processes has led to more efficient prevention of adverse health effects associated with the consumption or use of the products. For example, the implementation of an industry wide HACCP program

for seafood processors in the US is thought to have averted 20–60% of the normal number of seafood-borne illnesses (Birley & Lock, 1998). A similar program for the prevention of food-borne Listeriosis in the US reduced the incidence and mortality of this disease by 44% and 49% respectively over a period of four years (Billy, 1997).

Limited evidence suggests that implementation of HACCP-like processes will also reduce water-related disease incidence and outbreaks. For example, In the United States of America disease outbreaks associated with drinking water supplied from surface water decreased from 31.8% of all drinking water outbreaks in 1995 1996 to 11.8% in 1997–1998 (Barwick, Levy, Craun, Beach, & Calderon, 2000). Much of this reduction was attributed to a partnership between the US Environmental Protection Agency (EPA) and drinking water agencies to implement HACCP-like preventative procedures designed to optimise water treatment at their facilities (Barwick et al., 2000; Godfree, 2000). The USEPA Interim Enhanced Surface Water Treatment Rule (USEPA, 1998) also includes HACCP-like strategies for reducing drinking water related disease (Godfree, 2000). It is likely that further use of HACCP programmes in water treatment, water supply, and water reuse processes will have similar results. Deere, Stevens, Davison, Helm, and Dufour (2001) outline the development of a HACCP system for drinking water and present some case studies for identifying critical control points.

WHO has long recommended implementation of a multiple barrier approach similar to HACCP for protecting public health. In the meantime food producer HACCP plans should anticipate and address the limitations of the current safety control systems for water. Fortunately for the food industry potential threats to consumer safety from contaminated water are often mitigated to some degree by the subsequent downstream processes (critical control points) such as filtration and heat.

Improved management of water resources will likely lead to more water reuse. Water reuse is already occurring in both primary production and in the factory. Safe water reuse requires rigorous management approaches based on good science. Therefore, it will be important to ensure that safeguards are in place to maximize public health protection. WHO Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture provide a framework for producing food safely using reclaimed water.

WHO Guidelines for drinking water quality set microbial and chemical quality targets for potable water. Water is currently classified as either potable or non-potable. It would seem perfectly possible to argue that what is important is suitability for intended use. The need exists for food companies to have a framework based upon sound science to allow them to assess the potential for optimising water use and for assessing the potential impact of changes in water quality on their business. This framework must be based upon accepted risk assessment frameworks for chemical and microbiological hazards and be compatible with current HACCP protocols. It is important that the food industry work in collaboration with scientific experts and non-governmental organisations to develop the necessary framework. In the future, therefore, guidelines may be based around evaluating suitability for use. Options may include a scheme of water quality classification (i.e., not just potable and non-potable) based upon the potential of the water to come into contact with food and the likely outcomes of downstream food processing activities.

Application of the concepts of continuity of food supply chains, often expressed as "farm to fork", and integrated thinking is important if we are to meet our common objectives of continuing to improve public health. To be successful in this application the close collaboration of all involved in the activity of food supply, including the water sector, is essential.

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Further reading

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